R.0193

THE

ENCYCLOPÆDIA BRITANNICA

DICTIONARY

ARTS, SCIENCES, AND GENERAL LITERATURE

NINTH EDITION

VOLUME XVI

EDINBURGH: ADAM AND CHARLES BLACK
MDCCCLXXXIII

[*All Rights reserved*]

17497
300

Encyclopædia Britannica.

VOL. XVI.—(MEN–MOS).

Total number of Articles, 376

PRINCIPAL CONTENTS

- MENANDER F A Paley LL D
- MENCIUS James Legge LL D Professor of Chinese University of Oxford
- MENDELSSOHN W S Rockstro Author of Life of Handel
- MENSURATION Wm Thomson Professor of Mathematics Stellenbosch College South Africa
- MERCURY W Dittmar F R S Professor of Chemistry Anderson s College Glasgow
  - Therapeutic Uses D J Leech M D Professor of Materia Medica Owens College Manchester
- MERV Major F C H Clarke C M G R A
- MESOPOTAMIA Prof Albrecht Socin University of Tubingen
- MESSIAH Prof W Robertson Smith LL D
- METALLURGY Prof Dittmar
- METAL WORK J H Middleton M A London
- METAPHYSIC Edward Caird LL D Professor of Moral Philosophy University of Glasgow
- METASTASIO J A Symonds M A
- METEMPSYCHOSIS F A Paley LL D
- METEOR Hubert A Newton LL D Professor of Mathematics Yale College Conn
- METEOROLOGY A Buchan F R S E and Prof Balfour Stewart LL D F R S
- METHODISM Rev J H Rigg D D Author of Churchmanship of John Wesley
- METSU J A Crowe Author of Lives of Early Flemish Painters
- METTERNICH C Alan Fyffe M A Author of A History of Modern Europe
- MEXICO E B Tylor D C L LL D F R S and Prof A H Keane
- MEYERBEER W S Rockstro
- MICAH Prof W Robertson Smith
- MICHELANGELO Sidney Colvin M A Slade Professor of Fine Art University of Cambridge
- MICHIGAN C K Adams LL D Professor of History University of Michigan Ann Arbor Mich
- MICROMETER David Gill LL D F R S Astronomer Royal Cape of Good Hope
- MICROSCOPE W B Carpenter M D C B F R S Author of The Microscope and its Revelations
- MIDDLESEX H B Wheatley Secretary of the Topographical Society of London
- MIDRASH S M Schiller Szinessy M A
- MILITARY LAW J C O Dowd C B Deputy Judge Advocate General War Office London
- MILITIA J C O Dowd
- MILK Prof J G M Kendrick M D LL D and James Paton
- MILL JAMES Alexander Bain LL D Author of The Emotions and the Will
- MILL JOHN STUART Wm Minto M A Professor of Logic University of Aberdeen
- MILLENNIUM Adolf Harnack D D Professor of Church History University of Giessen
- MILLER HUGH Peter Bayne LL D Author of Life and Letters of Hugh Miller
- MILMAN Richard Garnett LL D
- MILTON Prof David Masson LL D Author of Life of John Milton
- MILWAUKEE J Johnston Milwaukee
- MIMICRY Grant Allen
- MINERALOGY M F Heddle M D Professor of Chemistry University of St Andrews
- MINERAL WATERS John Macpherson M D Author of Baths and Wells of Europe and Prof Albert R Leeds Stevens Institute of Technology *Hoboken N J*
- MINIATURE E Maunde Thompson LL D
- *MINING* C Le Neve Foster D Sc H M Inspector of Metalliferous Mines
- MINISTRY Alex C Ewald Record Office London
- MINNESOTA J G Pyle St Paul Minn
- MINSTREL Prof Minto
- MINT W Chandler Roberts F R S and R A Hill both of the Royal Mint London
- MIRABEAU H Morse Stephens
- MIRROR James Paton and A S Murray
- MISHNAH S M Schiller Szinessy
- MISSAL Rev J Sutherland Black M A
- MISSIONS Rev G F Maclear D D Warden of St Augustine College Canterbury
- MISSISSIPPI (River) Col H L Abbot U S Engineers
- MISSISSIPPI (State) Prof R B Fulton University of Mississippi Oxford Miss
- MISSOURI Prof M S Snow Washington University St Louis Mo
- MITE A D Michael F R M S
- MOAB Prof Julius Wellhausen University of Halle
- MOHAMMEDANISM—
  - Mohammed Prof Wellhausen
  - Eastern Caliphate Prof Stanislas Guyard
  - Koran Prof Noldeke
- MOLE Surgeon Major Dobson F R S
- MOLECULE Rev H W Watson M A Rector of Berkeswell Warwickshire S H Burbury M A Lincoln s Inn and Prof A Crum Brown
- MOLIÈRE Andrew Lang Author of Helen of Troy
- MOLLUSCA E Ray Lankester F R S Professor of Zoology University College London
- MOLOCH Prof W Robertson Smith
- MONACHISM Rev R F Littledale LL D D C L
- MONEY C F Bastable M A Prof of Jurisprudence and Political Economy Queen s College Galway
- MONGE Prof Arthur Cayley LL D D C L F R S
- MONGOLS R K Douglas Professor of Chinese King s College London and Prof B J L University of Innsbruck
- MONMOUTH DUKE OF Osmund Airy
- MONROE Prof Freeman Snow Harvard University, Cambridge Mass
- MONSTER Charles Creighton M A M D
- MONTAIGNE Geo Saintsbury
- MONTANA Henry Gannett, Geographical Department Washington
- MONTANISM Prof Harnack
- MONTENEGRO H A Webster.
- MONTESQUIEU G Saintsbury
- MONTREAL Prof Daniel Wilson LL D
- MONTROSE MARQUIS OF S R Gardiner Professor of Modern History King s College London
- MOON Simon Newcomb Professor of Astronomy U S Naval Observatory Washington
- MOORE SIR JOHN H M Stephens
- MOORE THOMAS Prof Minto
- MORAVIA J F Muirhead Leipsic
- MORAVIAN BRETHREN Prof T M Lindsay D D
- MORE HENRY Very Rev John Tulloch D D late Principal of St Mary s College St Andrews
- MORE THOMAS Rev Mark Pattison B D Rector of Lincoln College Oxford
- MORMONS Prof John Fraser University of Chicago
- MOROCCO H A Webster
- MORPHOLOGY Patrick Geddes F R S E
- MORSE. Rev S Irenæus Prime D D Author of Life of Morse
- *MORTGAGE* Edmund Robertson LL D M P Professor of Roman Law University College London
- MOSAIC J H Middleton
- MOSCOW P A Kropotkine
- MOSES Prof Wellhausen
- MOSES OF CHORENE Prof A von Gutschmid, University of Tubingen
- MOSQUE J H Middleton
- MOSQUITO R M Lachlan F R S

ENCYCLOPÆDIA BRITANNICA.

MENA, JUAN DE, one of the Italianizing Spanish poets of the 15th century, was born at Cordova about 1411 We are informed by Romero, to whom we are indebted for almost all we know about his life, that he had attained the age of twenty three before he began to give himself to "the sweet labour of good learning," pursuing a regular course of study at Salamanca and afterwards at Rome It was at the latter city that he first became acquainted with the writings of Dante and Petrarch, which afterwards so powerfully influenced his own style Having returned to Spain, he became a "veinticuatro," or magistrate, of his native town, and was received as a poet with great favour at the court of John II, being made Latin secretary to the king and historiographer of Castile He died suddenly, in consequence of a fall from his mule, in 1456, at Torrelaguna, where the marquis of Santillana, his friend and patron, erected his monument and wrote his epitaph De Mena's principal work, *El Laberinto* ("The Labyrinth"), sometimes called *Las Trescientas* ("The Three Hundred") from the original number of its stanzas, is a didactic allegory on the duties and destinies of man, obviously constructed on the lines of the *Divina Commedia* of Dante The poet, while wandering in a wood and exposed to the attacks of various beasts of prey, is met by Providence in the guise of a beautiful woman, who offers to guide him safely through the dangers which surround him, and at the same time to explain—"as far as they may be grasped by human understanding"—the dark mysteries of life that weigh upon his spirit He is then led to the spherical centre of the five zones, where he sees the three wheels of destiny, the past, the future, and the present, and the men belonging to each, arranged in the seven circles of planetary influence Opportunity is thus afforded for a vast quantity of mythological and historical portraiture the best sketches are those of the poet's own contemporaries, but the work in general is much disfigured with all sorts of pedantry, and hardly ever attains to mediocrity as a poem The *Laberinto* was first printed at Seville in 1496 Nunez and Sanchez accompanied it with commentaries in 1499 and 1582 respectively and it is still regarded with a good deal of reverence by the Spaniards as the "magnum opus" of their "Ennius" De Mena was the author of a number of minor poems or "vers de société," written merely for court circles, and having neither general interest nor permanent value, most of them are to be found in the *Cancionero General* He also wrote a poem entitled *La Coronacion*, the subject being the "crowning" of the marquis of Santillana by the Muses and the Virtues on Mount Parnassus Finally, his *Siete Pecados Mortales* ("Seven Deadly Sins") is a dull allegory on the antagonism between reason and the will of man Complete editions of the poems of De Mena appeared in 1528, 1804, and 1840

MÉNAGE, GILLES (1613–1692), described by Bayle as "one of the most learned men of his time, and the Varro of the 17th century," was the son of Guillaume Ménage, king's advocate at Angers, and was born in that city on August 15, 1613 A tenacious memory and an early developed enthusiasm for learning carried him speedily through his literary and professional studies, and we read of him practising at the bar at Angers as early as 1632 In the same year he pleaded several causes before the parlement of Paris, and soon afterwards he attended the "Grand Tours" at Poitiers, but after having been laid aside by a severe illness he abandoned the legal profession and declared his intention of entering the church He succeeded in obtaining some sinecure benefices, and lived for some years in the household of Cardinal De Retz (then only coadjutor to the archbishop of Paris), where he had ample leisure for his favourite literary pursuits Some time after 1648 he withdrew to a house of his own in the cloister of Notre Dame, where his remarkable conversational powers enabled him to gather round him on Wednesday evenings those much frequented literary assemblies which he called "Mercuriales" His learning procured for him admission to the Della Cruscan Academy of Florence but his irrepressible tendency to caustic sarcasm led to his remorseless exclusion from the French Academy He died at Paris on July 23, 1692 Of the voluminous works of Ménage (fully enumerated in the *Dictionnaire* of Chauffepié) the following may be mentioned *Origines de la Langue Française* (1650, greatly enlarged in 1694) *Diogenes Laertius Græce et Latine cum Commentario* (1663, and again much improved in 1692) *Poemata Latina Gallica, Græca et Italica* (1656 8th ed 1687), *Origini della Lingua Italiana* (1669) and *Anti Baillet* (1690)

After his death a volume of *Menagiana* was published, it was afterwards expanded into two, and, with great additions, into four in the Paris edition of 1715

MENANDER, the most famous Greek poet of the New Comedy, which prevailed from about the death of Alexander the Great (323 B C) to 250 He was born at Athens in 342, and died, it was said, by drowning in the harbour of that city (Piræus) in 291 His social tastes induced him to write plays rather for the upper classes, and to raise comedy to a gentility which it had hardly possessed in the hands of the preceding comic poets He was the associate, if not the pupil, of Theophrastus, who himself had been a disciple of Plato and Aristotle, and he was the intimate friend and admirer of Epicurus but he also enjoyed the more distinguished patronage of Demetrius Phalereus (who was likewise a pupil of Theophrastus), and of Ptolemy the son of Lagus[1] His principal rival in the art was Philemon, who appears to have been more popular with the multitude, and for that reason probably more successful It is said that out of a hundred comedies Menander gained the prize with but eight All the extant plays of Terence, with the exception of the *Phormio*, are avowedly taken from Menander but some of them appear to have been adaptations and combinations of more than one plot, although Terence himself says in the prologue to the *Adelphi* (11) that he copied the Greek model closely, 'verbum de verbo expressum extulit Julius Cæsar called Terence *dimidiatus Menander*, as if two halves of different plays had been fitted into one[2]

The Attic New Comedy, says Dr Wagner,[3] "may be designated as essentially domestic, *i e*, as opposed to that free discussion of the politics of the day which gave to the Old Comedy the place which is held by the 'leading articles' of a modern newspaper 'The stock characters were such as the stern or weak father, the son whose follies are seconded by a slave or a hungry parasite, the pettifogger, active in stirring up law suits, and the gascon ading soldier of fortune[4] These and cognate subjects, which formed the stock in trade of Menander's plays, are summed up in two well known lines of Ovid—

"Dum fallax servus durus pater improba lena
Vivet, dum meretrix blanda Menandros erit

It is a good remark of Dr Wagner's that the last mentioned of these, the *meretrix blanda* (which probably refers especially to the *Thais*), 'holds the most important and conspicuous part in the New Attic Comedy, while married ladies are continually represented as the plague and bore of their husbands lives" Intrigues with these, generally through the medium of a clever confidential slave, are for the most part the very point or pivot on which the plot turns

The more literary Romans greatly admired Menander as a poet Pliny (*N H*, xxx 1, § 7) speaks of him as 'Menander litterarum subtilitati sine æmulo genitus' Propertius, contemplating a visit to Athens,[6] anticipates the pleasure of reading Menander in his native city—

"Persequar aut studium linguæ Demosthenis arma,
Libiboque tuos, scite Menandre sales

He elsewhere speaks of him as "mundus Menander," neat, terse, and urbane and his skill in depicting the character of a fascinating Thais is alluded to here and in ii 6, 3 —

'Turba Menandreæ fuerat nec Thaidos olim
Tanta, in qua populus lusit Erichthonius

Of this comedy, the *Thais*, Professor Mahaffy remarks[7] that perhaps it was the most brilliant of Menander's plays, "the manners and characters of the personage being painted with thorough experience as well as genius" Nevertheless, only five verses of this play have been preserved to us, one of which is that quoted by St Paul (1 Cor xv 33), "Evil communications corrupt good manners" The same critic, in praising Menander's style as the purest model of the New Attic, observes that a remarkable feature of the New Comedy was "its utter avoidance of rhetoric' (p 489) The influence which this art had on Euripides is well known Sophocles was not wholly exempt from a kind of rhetorical pedantry, and the speeches in Thucydides are so many exercises of the author in that art But, as rhetoric pertained essentially to public life, it was likely to have a much less scope in scenes borrowed almost solely from social and domestic experiences

Menander, however, did not neglect the other branch of a liberal Attic education,—philosophy A follower and a friend of Epicurus, whose *summum bonum* was the greatest amount of enjoyment to be got out of life, he carried out in practice what he advocated by precept, for he was essentially the well to do gentleman,[8] and moved in the upper circles of Athenian society "The philosophers of the day (*i e*, the schools and universities in our modern systems of teaching) 'were still," says Professor Mahaffy,[9] viz, even during the period of the New Comedy, "the constant butt of the dramatists' He adds that, "what is still stranger, political attacks on living personages, not excepting Alexander the Great, were freely and boldly made'

On the whole, our estimate of the spirit and object of Menander must be formed rather from his imitator and copyist Terence than from the fragments which remain about 2400 verses in all, as collected by Meineke in his *Fragmenta Comicorum Græcorum* For, as Professor Mahaffy well observes,[10] the extracts made by Athenæus our principal authority, have reference chiefly to "the archæology of cooks and cookery while Stobæus was a collector of γνωμαι or wise maxims —' a most unfortunate and worthless kind of citation It follows that no sound conclusions as to dramatic genius, or of the knowledge of human nature can be drawn from detached verses preserved without the least reference to these particular points The extraordinary popularity of Menander must have been due to literary merit if not to great originality Mr Mahaffy observes on this[11] that 'there is so much of a calm gentle manly morality about his fragments he is so excellent a teacher of the ordinary world wisdom—resignation, good temper moderation friendliness—that we can well understand this popularity Copies of his plays continued long in existence, and were certainly known to Suidas and Eustathius as late as the 11th and 12th centuries if they did not survive to a yet later period[12]

In respect of language Menander occupies the same position in poetry which his contemporary Demosthenes does in prose In both the New Attic is elaborated with great finish and with much greater grammatical precision than we find in writers of the Old Attic, such as Sophocles and Thucydides A considerable addition to the vocabulary of every day life had now been made, as was indeed inevitable from the versatile character of the language and the genius of the people who used it Many new verb forms especially the perfect active[13] now occur and indeed form a characteristic innovation of the style of Plato The earlier prose was in its general vocabulary to a considerable extent poetical and such a concurrence of short syllables as in the Platonic αποδεδοκιμακοτες

---

[1] In allusion to this Pliny writes (*N H*, vii 30 § 111) 'Magnum et Menandro in comico socco testimonium regum Ægypti et Macedoniæ contigit classe et per legatos petito majus ex ipso, regiæ fortunæ prælata litterarum conscientia This seems to say that Menander had been invited to the courts of Alexander and Ptolemy as Euripides had been to that of Archelaus king of Macedonia but had preferred to write comedies for the Attic stage

[2] Thus the *Andria Heautontimorumenos* and *Hecyra* are described severally in the *tituli* prefixed as *Græca* or *tota Græca Menandru* The *Eunuch* and *Timorumenos* are each based on two plays of Menander, and the *Adelphi* was compiled partly from Menander and partly from Diphilus

[3] *Introduction to Terence*, p 6 (Bell 1869)

[4] Professor Jebb, *Primer of Greek Literature*, p 101

[5] *Ut sup*, p 7

[6] *El*, iv 21 27

[7] *Hist Class Gr Lit*, i p 488

[8] Pliny calls Menander 'diligenti[illegible]s luxuriæ interpres, *N H*, xxxvi 5

[9] *Hist Class Gr Lit*, i p 480

[10] *Ibid*, p 480

[11] *Ibid*, p 487

[12] *Ibid*, p 490

[13] A curious example is απεκτάγκασι, the transitive perfect of αποκτεινειν Similarly we have the unusual forms κεχρηκα (frag 559) εψόφηκ (727), συγκεχυκα (810)

(ἀποδοκιμάζειν) is ill suited even to choral metre. The Old Comedy was worked by men of real genius, who "were indeed giants, while the men of Menander's day only showed how strong and thorough was the culture which in art and literature outlived the decadence of the nation."[1]

In all, we have, as collected by Meineke, 1045 fragments of Menander, of which 515 can be referred to known plays, the titles of those quoted from amounting to ninety, and including the Terentian *Andria*, *Adelphi*, *Eunuchus*, *Heautontimorumenos*. These fragments contain about 1650 verses or parts of verses, not including a considerable number of words quoted expressly as from Menander by the old lexicographers. Besides all these there are not fewer than 758 monostich verses separately preserved in MSS., though some of these are met with in the other and longer fragments. Many of the fragments are obscure, some corrupt, and they have been a fertile field for critical acumen from the time of Bentley. Not unfrequently we come upon the shrewd or original remark of an observer. Thus (frag. 7) "A poor man has no relations, for no one acknowledges him, lest he should beg." Frag. 145 "Everything that takes place is brought about by law, necessity, or fashion." 237, "The gods do not save men through any human means (prayer or sacrifices), if they did, the human would have more power than the divine." 275 "Poverty is the most easily cured of all evils, any friend can do it by merely putting his hand in his pocket." 397, "A poor man who lives in a large town makes himself more wretched than he need, for he cannot help comparing with his own the luxurious lives of the rich." 435, "No man realizes the extent of a sin when he commits it, it is afterwards that he sees it." 460 "A man is convinced not so much by what is said as by the manner of saying it." 474, "There is one thing only that hides vulgarity, villainy and every other fault,—wealth. Everything but that is carped at and criticized." 517, "People who have no merit of their own generally boast of their birth and their ancestors. But every living man has ancestors, or he would not be a living man." 578, "Wealth acts on a man as wind does on a ship, it often forces him out of his proper course." 663, "Many a young lady says a great deal in her own favour by saying nothing at all." 698, "A man who abuses his own father is practising blasphemy against the gods." In fact Menander is characteristically a sententious writer, like Euripides, with whom in the general style of his writings though not, of course, in his somewhat loose and irregular versification, he is sometimes compared. (F. A. P.)

MENCIUS, the Latinized form of Măng tsze, "Mr Măng," or "Măng the philosopher," a name in China only second as a moral teacher to that of Confucius. His statue or spirit tablet (as the case may be) has occupied, in the temples of the sage, since our 11th century, a place among "the four assessors", and since 1530 A.D. his title has been "the philosopher Măng, sage of the second degree."

The Măngs or Măng suns had been in the time of Confucius one of the three great clans of Lû (all descended from the marquis Hwan, 711–694 B.C.), which he had endeavoured to curb. Their power had subsequently been broken, and the branch to which Mencius belonged had settled in Tsau, a small adjacent principality, the name of which still remains in Tsau hsien, a district of Yenchâu Shantung. A magnificent temple to Mencius is the chief attraction of the district city. The present writer visited it in 1873, and was struck by a large marble statue of him in the courtyard in front. It shows much artistic skill, and gives the impression of a man strong in body and mind, thoughtful and fearless. His lineal representative lives in the city, and thousands of Măngs are to be found in the neighbourhood.

The dates of some of the principal events in Mencius's life are fixed by a combination of evidence, and his death is referred by common consent to the year 289 B.C. He had lived to a great age,—some say to his eighty fourth year, placing his birth in 372 B.C., and others to his ninety-seventh, placing it in 385. All that we are told of his father is that he died in the third year of the child, who was thus left to the care of his mother. She was a lady of superior character, and well discharged her trust. Her virtues and dealings with her son were celebrated by a great writer in the first century before our era, and for two thousand years she has been the model mother of China.

We have no accounts of Mencius for many years after his boyhood, and he is more than forty years old when he comes before us as a public character. He must have spent much time in study, investigating the questions which were rife as to the fundamental principles of morals and society, and brooding over the condition of the country. The history, the poetry, the institutions, and the great men of the past had received his careful attention. He intimates that he had been in communication with men who had been disciples of Confucius. That sage had become to him the chief of mortal men, the object of his untiring admiration, and in the doctrines which he had taught Mencius recognized the truth for want of an appreciation of which the bonds of order all round him were being relaxed, and the kingdom hastening to a general anarchy.

When he first comes forth from Tsau, he is accompanied by several eminent disciples. He had probably imitated Confucius in becoming the master of a school, and encouraging the resort to it of inquiring minds that he might resolve their doubts and unfold to them the right methods of government. One of his sayings is that it would be a greater delight to the superior man to get the youth of brightest promise around him and to teach and train them than to enjoy the revenues of the kingdom. His intercourse with his followers was not so intimate as that of Confucius had been with the members of his selected circle, and, while he maintained his dignity among them, he was not able to secure from them the same homage and reverent admiration.

More than a century had elapsed since the death of Confucius, and during that period the feudal kingdom of Chau had been showing more and more of the signs of dissolution, and portentous errors that threatened to upset all social order were widely disseminated. The sentiment of loyalty to the dynasty had disappeared. Several of the marquises and other feudal princes of earlier times had usurped the title of king. The smaller fiefs had been absorbed by the larger ones, or reduced to a state of helpless dependence on them. Tsin, after greatly extending its territory, had broken up into three powerful kingdoms, each about as large as England. Mencius found the nation nominally one, and with the traditions of two thousand years affirming its essential unity, but actually divided into seven monarchies, each seeking to subdue the others under itself. The consequences were constant warfare and chronic misery.

In Confucius's time we meet with recluses who had withdrawn in disgust from the world and its turmoil, but these had now given place to a class of men who came forth from their retirements provided with arts of war or schemes of policy which they recommended to the contending chiefs, ever ready to change their allegiance as they were moved by whim or interest. Mencius was once asked about two of them, "Are they not really great men? Let them be angry, and all the princes are afraid. Let them live quietly, and the flames of trouble are everywhere extinguished." He looked on them as little men, and delighted to proclaim his idea of the great man in such language as the following:—

> "To dwell in love, the wide house of the world, to stand in propriety, the correct seat of the world, and to walk in righteousness, the great path of the world; when he obtains his desire for office, to practise his principles for the good of the people, and when that desire is disappointed, to practise them alone; to be above the power of riches and honours to make dissipated, of poverty and mean condition to make swerve from the right, and of power and force to make bend,—these characteristics constitute the great man."

Most vivid are the pictures which Mencius gives of the condition of the people in consequence of the wars of the states. "The royal ordinances were violated; the multi tudes were oppressed, the supplies of food and drink flowed away like water." It is not wonderful that, when the foundations of government were thus overthrown, speculations should have arisen that threatened to overthrow what he considered to be the foundations of truth and all social order. "A shrill-tongued barbarian from the south," as Mencius called him, proclaimed the dissolution of ranks, and advocated a return to the primitive simplicity,

---

[1] Mahaffy, *Ibid.*, p. 490.

"When Adam delved and Eve span.

He and his followers maintained that learning was quackery, and statesmanship craft and oppression, that prince and peasant should be on the same level, and every man do everything for himself. Another, called Yang-chû, denied the difference between virtue and vice, glory and shame. The tyrants of the past, he said, were now but so many rotten bones, and the heroes and sages were no more. It was the same with all at death; after that there was but so much putridity and rottenness. The conclusion of the whole matter therefore was: "Let us eat and drink; let us gratify the ears and eyes; get servants and maidens, beauty, music, wine; when the day is insufficient, carry it on through the night. Each one for himself." Against a third heresiarch, of a very different stamp, Mencius felt no less indignation. This was Mo Tî, who found the source of all the evils of the time and of all time in the want of mutual love. He taught, therefore, that men should love others as themselves; princes, the states of other princes as much as their own; children, the parent of others as much as their own. Mo, in his gropings, had got hold of a noble principle, but he did not apprehend it distinctly nor set it forth with discrimination. To our philosopher the doctrine appeared contrary to the Confucian orthodoxy about the five relations of society, and he attacked it without mercy and with an equal confusion of thought. "Yang's principle," he said, "is 'each one for himself,' which does not acknowledge the claims of the sovereign. Mo's is 'to love all equally,' which does not acknowledge the peculiar affection due to a father. But to acknowledge neither king nor father is to be in the state of a beast. The way of benevolence and righteousness is stopped up."

On this seething ocean of lawlessness, wickedness, heresies, and misery Mencius looked out from the quiet of his school, and his spirit was stirred within him to attempt the rescue of the people from the misrule and error. It might be that he would prove the instrument for this purpose. "If Heaven," he said, "wishes that the kingdom should enjoy tranquillity and good order, who is there besides me to bring it about?" He formed his plan, and proceeded to put it in execution. He would go about among the different kings till he should find one among them who would follow his counsels and commit to him the entire administration of his government. That obtained, he did not doubt that in a few years there would be a kingdom so strong and so good that all rulers would acknowledge its superiority, and the people hasten from all quarters to crown its sovereign as monarch of the whole of China. This plan was much the same as that of Confucius had been; but, with the bolder character that belonged to him, Mencius took in one respect a position from which "the master" would have shrunk. The former was always loyal to Châu, and thought he could save the country by a reformation; the latter saw the day of Châu was past, and the time was come for a revolution. Mencius's view was the more correct, but he was not wiser than the sage in forecasting for the future. They could think only of a reformed dynasty or of a changed dynasty, ruling according to the model principles of a feudal constitution, which they described in glowing language. They desired a repetition of the golden age in the remote past, but soon after Mencius disappeared from the stage of life there came the sovereign of Ch'in, and solved the question with fire and sword, introducing the despotic empire which has since prevailed.

An inquiry here occurs—"How, in the execution of his plan, was Mencius, a scholar, without wealth or station, to find admission to the courts of lawless and unprincipled kings, and acquire the influence over them which he expected?" It can only be met by our bearing in mind the position accorded from the earliest times in China to men of virtue and ability. The same written character denotes both scholar and officers. They are at the top of the social scale,—the first of the four classes into which the population has always been divided. This appreciation of learning or culture has exercised a most powerful influence over the government under both conditions of its existence, and out of it grew the system, which was organized and consolidated more than a thousand years ago, of making literary merit the passport to official employment. The ancient doctrine was that the scholar's privilege was from Heaven as much as the sovereign's right; the modern system is a device of the despotic rule to put itself in Heaven's place, and have the making of the scholar in its own hands. The feeling and conviction out of which the system grew prevailed in the time of Mencius. The dynasties that had successively ruled over the kingdom had owed their establishment not more to the military genius of their founders than to the wisdom and organizing ability of the learned men, the statesmen, who were their bosom friends and trusted counsellors. Why should not he become to one of the princes of his day what Î Yin had been to Thang, and Thai-kung Wang to King Wân, and the duke of Châu to Wû and Ch'ăng? But, though Mencius might be the equal of any of those worthies, he knew of no prince like Thang and the others, of noble aim and soul, who would welcome and adopt his lessons. In his eagerness he overlooked this condition of success for his enterprise. He might meet with such a ruler as he looked for, or he might reform a bad one, and make him the coadjutor that he required. On the strength of these peradventures, and attended by several of his disciples, Mencius went for more than twenty years from one court to another, always baffled, and always ready to try again. He was received with great respect by kings and princes. He would not enter into the service of any of them, but he occasionally accepted honorary offices of distinction, and he did not scruple to receive large gifts which enabled him to live and move about as a man of wealth. In delivering his message he was as fearless and outspoken as John Knox. He lectured great men, and ridiculed them. He unfolded the ways of the old sage kings, and pointed out the path to universal sway; but it was all in vain. He could not stir any one to honourable action. He confronted heresy with strong arguments and exposed it with withering sarcasm, but he could work no deliverance in the earth. The last court at which we find him was that of Lû, probably in 310 B.C. The marquis of that state had given office to Yo-chăng, one of Mencius's disciples, and he hoped that this might be the means of a favourable hearing for himself. So it had nearly happened. On the suggestion of Yo-chăng the marquis had ordered his carriage to be yoked, and was about to step into it, and proceed to bring Mencius to his palace, when an unworthy favourite stepped in and diverted him from his purpose. The disciple told his master what had occurred, reproaching the favourite for his ill-timed intervention. Mencius, however, said to him, "A man's advancement or the arresting of it may seem to be *effected by others, but is really beyond their power.* My not finding in the marquis of Lû a ruler who would confide in me and put my lessons in practice is from Heaven" He accepted this incident as a final intimation to him of the will of Heaven He had striven long against adverse circumstances, but now he bowed in submission We lose sight of him He withdrew from courts and the public arena We have to think of him, according to tradition, passing the last twenty years of his life in the congenial society of his disciples, discoursing to them, and giving the finishing touches to the record of his conversations and opinions, which were afterwards edited by them, and constitute his works Living, he may have been a failure, dead, yet speaking in them, he has been a great power among the ever multiplying millions of his countrymen Nor will any thinker of the West refer to them without interest and benefit Mencius was not so oracular, nor so self contained, as Confucius, but his teachings have a vivacity and sparkle of which we never weary, and which is all their own

We will now attempt to indicate briefly the more important principles which our philosopher thought would have been effectual to regenerate his country, and make an end of misery and heresy within its borders

And first as to his views on government, and the work to be done by rulers for their subjects Mencius held with Confucius—and it was a doctrine which had descended to them both from the remotest antiquity—that royal government is an institution of God An ancient sovereign had said that "Heaven, having produced the people appointed for them rulers, and appointed for them teachers, who should be assisting to God Our philosopher, adopting this doctrine, was led by the manifest incompetency of all the rulers of his time to ask how it could be known on what individual the appointment of Heaven had fallen or ought to fall and he concluded that this could be ascertained only from his personal character and his conduct of affairs The people must find out the will of Heaven as to who should be their ruler for themselves There was another old saying which delighted Mencius — 'Heaven sees as the people see Heaven hears as the people hear' He taught accordingly that while government is from God, the governors are from the people —*vox populi vox Dei*

No claim then of a "divine right should be allowed to a sovereign if he were not exercising a rule for the good of the people 'The people are the most important element in a nation the altars to the spirits of the land and grain are the second, the sovereign is the lightest" Mencius was not afraid to follow this utterance to its consequences The monarch whose rule is injurious to the people, and who is deaf to remonstrance and counsel should be dethroned In such a case killing is no murder

But who is to remove the sovereign that thus ought to be removed? Mencius had three answers to this difficult question First, he would have the members of the royal house perform the task Let them disown their unworthy head, and appoint some better individual of their number in his room If they could not or would not do this, he thought, secondly, that any high minister though not allied to the royal house, might take summary measures with the sovereign, assuming that he acted purely with a view to the public weal His third and grand device was what he called 'the minister of Heaven' When the sovereign had become a pest instead of a blessing he believed that Heaven would raise up some one for the help of the people, some one who should so conduct himself in his original subordinate position as to draw all eyes and hearts to himself Let him then raise the standard not of rebellion but of righteousness, and he could not help attaining to the highest dignity Mencius hoped to find one among the rulers of his day who might be made into such a minister and he counselled one and another to adopt measures with that object It was in fact counselling rebellion, but he held that the house of Châu had forfeited its title to the throne

What now were the attributes which Mencius considered necessary to constitute a good government according to his ideal of it? It must be animated by a spirit of benevolence, and ever pursue a policy of righteousness Its aims must be, first, to make the people well off, and next, to educate them No one was fit to occupy the throne who could be happy while any of the people were miserable, who delighted in war, who could indulge in palaces and parks which the poorest did not in a measure share with him Game laws received his emphatic condemnation Taxes should be light, and all the regulations for agriculture and commerce of a character to promote and encourage them The rules which he suggested to secure those objects had reference to the existing condition of his country, but they are susceptible of wide application They carry in them schemes of drainage and irrigation for land, and of free trade for commerce But it must be, he contended, that a sufficient and certain livelihood be secured for all the people Without this their minds would be unsettled, and they would proceed to every form of wild licence They would break the laws, and the ruler would punish them,—punish those whom his neglect of his own duties had plunged into poverty, of which crime was the consequence. He would be, not their ruler, but their "trapper'

Supposing the people to be made well off, Mencius taught that education should be provided for them all He gave the marquis of Thang a programme of four kinds of educational institutions, which he wished him to establish in his state—in the villages and the towns, for the poor as well as the rich, so that none might be ignorant of their duties in the various relations of society But after all, unless the people could get food and clothing by their labour, he had not much faith in the power of education to make them virtuous Give him, however, a government fulfilling the conditions that he laid down, and he was confident there would soon be a people, all contented, all virtuous And he saw nothing to prevent the realization of such a government Any ruler might become, *if he would*, "the minister of Heaven, who was his ideal, and the influence of his example and administration would be all powerful The people would flock to him as their parent and help him to do justice on the foes of truth and happiness Pulse and grain would be abundant as water and fire, and the multitudes, well clothed, and well principled, would sit under the shade of their mulberry trees, and hail the ruler "king by the grace of Heaven

Secondly, as to Mencius's views about human nature His conviction of the goodness of that encouraged him to hope for such grand results from good government, and his discussion of this subject gives his principal title to a place among philosophical thinkers

Opinions were much divided about it among his contemporaries Some held that the nature of man is neither good nor bad, he may be made to do good and also to do evil Others held that the nature of some men is good and that of others bad, thus it is that the best of men sometimes have bad sons and the worst of men good sons It was also maintained that the nature of man is evil, and whatever good appears in it is the result of cultivation In opposition to all these views Mencius contended that the nature of man is good 'Water, he said, 'will flow indifferently to the east or west but will it flow indifferently up or down? The tendency of man's nature to goodness is like the tendency of water to flow downwards By striking water you may make it leap over your forehead and by damming and leading it you may make it go up a hill But such movements are not according to the nature of water it is the force applied which causes them When men do what is not good, their nature has been dealt with in this way

Mencius had no stronger language than this,—as indeed it would be difficult to find any stronger —to declare his belief of the goodness of human nature With various but equally felicitous, illustration he replied to his different opponents Sometimes he may seem to express himself too strongly but an attentive study of his writings shows that he is speaking of our nature in its ideal, and not as it actually is —as we may ascertain, by an analysis of it that it was intended to be, and not as it has been made to become In fact his doctrine of human nature is hardly to be distinguished from that of Bishop Butler while the Christian prelate is left far behind so far as charm of style is concerned

Our author insists on the constituents of human nature dwelling especially on the principles of benevolence righteousness, propriety and wisdom or knowledge the last including the judgment of conscience "These, said he are not infused into us from without Men have these four principles just as they have their four limbs' But man has also instincts and appetites which seek their own gratification without reference to righteousness or any other control He met this difficulty by contending that human nature is a constitution, in which the higher principles are designed to rule the lower Some constituents of it are noble and some ignoble, some great and some small The great must not be injured for the small, nor the noble for the ignoble

One of his most vigorous vindications of his doctrine is the following – "For the mouth to desire flavours the eye colours, the ear sounds, and the four limbs ease and rest belong to man's nature An individual's lot may restrict him from the gratification of them and in such a case the superior man will not say My nature demands that pleasure and I *will* get it On the other hand, there are love between father and son, righteousness between ruler and minister, the rules of ceremony between host and guest, and knowledge seen in recognizing the able and virtuous and in the sage's fulfilling the heavenly course, –these are appointed (by Heaven) But they also belong to our nature and the superior man will not say, The circumstances of my lot relieve me from them " In his preliminary dissertation to the 7th edition of this encyclopædia, Sir James Mackintosh has said that in his sermons on human nature Butler taught truths more worthy of the name of discovery than any in the same department of inquiry with which we are acquainted, if we ought not to except the first steps of the Grecian philosophers towards a theory of morals. Mencius was senior to Zeno, the one of those philosophers to whom Butler has most affinity, and it does not appear that he had left anything for either of them to discover.

When he proceeded from his ideal of human nature to account for the phenomena of conduct so different from what they ought to be according to that ideal, he was necessarily less successful. They puzzled him and they made him indignant and angry. "There is nothing good," he said, "that a man cannot do. He only does not do it." But why does he not do it? Against the stubborn fact Mencius beats his wings and shatters his weapons,—all in vain. He mentions a few ancient worthies who he conceived had always been, or who had become, perfectly virtuous. Above them all he extols Confucius, taking no notice of that sage's confession that he had not attained to conformity to his own rule of doing to others as he would have them do to him. No such acknowledgment about himself ever came from Mencius. Therein he was inferior to his predecessor. He had a subtler faculty of thought and a much more vivid imagination, but he did not know himself nor his special subject of human nature so well.

Our limits will not allow us to go into a detail of his views on other special subjects. A few passages illustrative of his style and general teachings will complete all that can be said of h[illegible] His thoughts indeed were seldom condensed like tho[illegible] master into aphorisms and should be read in their conne[illegible] but we have from him many words of wisdom that have be[illegible] guides to millions for more than two thousand years. [illegible] stance:—

"Though a man may be wicked, yet if he adjust his thoughts, fast, and bathe, he may sacrifice to God."

"When Heaven is about to confer a great office on any man, it first exercises his mind with suffering and his sinews and bones with toil. It exposes his body to hunger, subjects him to extreme poverty, and [illegible]ds his undertakings. In all thes[illegible] stimulates his mind, strengthe[illegible] natu[illegible] supplies [illegible] competen[illegible]"

"The great man is he who does not lose his child heart."

"The [illegible]d shame is to a man of great importance. When one is ashamed of having been without shame, he will afterwards not have occasion for shame."

"To nourish the heart there is nothing better than to keep the desires few. Here is a man whose desires are few:—in some things he may not be able to keep his heart, but they will be few. Here is a man whose desires are many:—in some things he may be able to keep his heart, but they will be few."

"Benevolence is the distinguishing characteristic of man. As embodied in his conduct, it may be called the path of duty."

"There is an ordination for everything, and a man should receive submissively what may be correctly ascribed thereto. He who has the correct idea of what Heaven's ordination is will not stand beneath a tottering wall. Death sustained in the discharge of one's duties may be correctly ascribed to Heaven. Death under handcuffs and fetters cannot be correctly so ascribed."

"When one by force subdues men, they do not submit to him in heart. When he subdues them by virtue, in their hearts core they are pleased, and sincerely submit."

Two translations of the works of Mencius are within the reach of European readers,—that by the late Stanislas Julien in Latin (Paris, 1824), and that forming the second volume of Legge's *Chinese Classics* (Hong Kong, 186[illegible]). The latter has been published at London (18[illegible]) without the Chinese text. See also E. Faber, *The Mind of Mencius, or Political Economy founded upon Moral Philosophy*, translated from the German by A. B. Hutchinson (London, 188[illegible]). (J. LL.)

MENDELSSOHN, FELIX (1809-1847). Jakob Ludwig Felix Mendelssohn Bartholdy, one of the greatest composers of this century, was the grandson of Moses Mendelssohn noticed below, and was born in Hamburg on February 3, 1809.

In consequence of the troubles caused by the French occupation of Hamburg, Abraham Mendelssohn, his father, migrated in 1811 to Berlin, where his grandmother, Fromet, then in the twenty-fifth year of her widowhood, received the whole family into her house, No. 7 Neue Promenade. Here the little Felix and his sister Fanny received their first instruction in music from their mother, under whose care they progressed so rapidly that the altogether exceptional character of their talent soon became unmistakably apparent. Their next teacher was Madame Bigot, who, during the temporary residence of the family in Paris in 1816, gave them some valuable instruction. On their return to Berlin they took lessons in thoroughbass and composition from Zelter, in pianoforte playing from Ludwig Berger, and in violin playing from Henning,—the care of their general education being entrusted to the father of the novelist Paul Heyse.

Felix first played in public on the 24th of October 1818, taking the pianoforte part in a trio by Woelfl. On April 11, 1819, he entered the Berlin Singakademie as an alto, and in the following year began to compose with extraordinary rapidity. His earliest dated work is a cantata, *In ruhrend feierlichen Tonen*, completed on January 13, 1820. During that year alone he produced nearly sixty movements, including songs, pianoforte sonatas, a trio for pianoforte, violin, and violoncello, a sonata for violin and pianoforte, pieces for the organ, and even a little dramatic piece in three scenes. In 1821 he wrote five symphonies for stringed instruments, each in three movements, motetts for four voices, an opera, in one act, called *Soldatenliebschaft*, another, called *Die beiden Padagogen*, part of a third, called *Die wandernde Comodianten*, and an immense quantity of other music of different kinds, some of which, thought worthy of publication by the editors of his posthumous works, now stands before the world in evidence of the precocity of his genius. The original autograph copies of these early productions are now preserved in the Berlin Library, where they form part of a collection which fills forty-four large volumes, all written with infinite neatness, and for the most part carefully dated—a sufficient proof that the methodical habits which distinguished his later life were formed in early childhood.

In 1821 Mendelssohn paid his first visit to Goethe, with whom he spent sixteen days at Weimar, in company with Zelter. From this year also dates his first acquaintance with Weber, who was then in Berlin superintending the production of *Der Freischutz*, and from the summer of 1822 his introduction, at Cassel, to another of the greatest of his contemporaries, Ludwig Spohr. During this year his pen was even more prolific than before, producing, among other works, an opera, in three acts, entitled *Die beiden Neffen, oder Der Onkel aus Boston*, and a pianoforte concerto, which he played in public at a concert given by Frau Anna Milder.

It had long been a custom with the Mendelssohn family to give musical performances on alternate Sunday mornings in their dining room, with a small orchestra, which Felix always conducted, even when he was not tall enough to be seen without standing upon a stool. For each of these occasions he produced some new work,—playing the pianoforte pieces himself, or entrusting them to Fanny, while his sister Rebecka sang, and his brother Paul played the violoncello. In this way *Die beiden Neffen* was first privately performed, on the fifteenth anniversary of his birthday, February 3, 1824. Between the 3d and the 31st of March, in this year, he composed his fine symphony in C minor, now known as Op. 10, and soon afterwards the quartett in B minor, Op. 3, and the (posthumous) pianoforte sestett, Op. 110. In this year also began his lifelong friendship with Moscheles, who, when asked to receive him as a pupil, said, "If he wishes to take a hint from me, as to anything new to him, he can easily do so; but he stands in no need of lessons."

In 1825 Abraham Mendelssohn took Felix to Paris, where among other musicians then resident in the French capital he met the two most popular dramatic composers of the age, Rossini and Meyerbeer, and lived on terms of intimacy with Hummel, Kalkbrenner, Rode, Baillot, Herz, and many other artists of European celebrity. On this occasion, also, he made his first acquaintance with Cherubini, who, though he rarely praised any one, expressed a very high opinion of his talent, and recommended him to write a *Kyrie*, for five voices, with full orchestral accompaniments, which he himself described as "exceeding in thickness" anything he had attempted. From letters written at this period we learn that Felix's estimate of the French school of music was very far from a flattering one; but he formed some friendships in Paris, which were pleasantly renewed on later occasions. He returned to Berlin with his father in May 1825, taking leave of his Parisian friends on the 19th of the month, and interrupting his journey at Weimar for the purpose of paying a second visit to Goethe, to whom he dedicated his quartett in B minor. On reaching home he must have fallen to work with greater zeal than ever; for on the 23d of July in this same year he completed his pianoforte capriccio in F sharp minor (Op. 5), and on the 10th of August an opera, in two acts, called *Die Hochzeit des Camacho*, a work of considerable importance, concerning which we shall presently have to speak more particularly.

No ordinary boy could have escaped uninjured from the snares attendant upon such a life as that which Mendelssohn now lived. Notwithstanding his overwhelming passion for music, his general education had been so well cared for that he was able to hold his own, in the society of his seniors, with the easy grace of an accomplished man of the world. He was already recognized as a leading spirit by the artists with whom he associated; and these artists were men of acknowledged talent and position. The temptations to egoism by which he was surrounded would have rendered most clever students intolerable. But the natural amiability of his disposition and the healthy influence of his happy home life counteracted all tendencies towards inordinate self assertion; and he is described by all who knew him at this period as the most charming boy imaginable. Even Zelter, though by nature no less repressive than Cherubini, was not ashamed to show that he was proud of him; and Moscheles, whose name was already famous, met him from the first on equal terms.

Soon after his return from Paris Abraham Mendelssohn removed from his mother's residence to No. 3 Leipziger Strasse, a roomy, old fashioned house containing an excellent music room, and in the grounds adjoining a "Gartenhaus" capable of accommodating several hundred persons at the Sunday performances.[1] In the autumn of the following year this "garden house" witnessed a memorable private performance of the work by means of which the greatness of Mendelssohn's genius was first revealed to the outer world—the overture to Shakespeare's *Midsummer Night's Dream*. The finished score of this famous composition is dated "Berlin, August 6, 1826"—that is to say, three days after its author had attained the age of seventeen years and a half. Yet we may safely assert that in no later work does he exhibit more originality of thought, more freshness of conception, or more perfect mastery over the details of technical construction than in this delightful inspiration, which, though now nearly sixty years old, still holds its place at the head of the most brilliant achievements of our modern schools. The overture was first publicly performed at Stettin in February 1827, under the direction of the young composer, who, with this bright patent of artistic nobility to support his claim, was at once accepted as the leader of a new and highly characteristic manifestation of the spirit of modern progress. Henceforth therefore we must speak of him, not as a student, but as a mature and experienced artist.

Meanwhile *Camacho's Wedding* had been submitted to Herr General Musik Director Spontini, with a view to its production at the opera. The libretto, founded upon an episode in the history of Don Quixote, was written by Klingemann, and Mendelssohn threw himself into the spirit of the romance with a keen perception of its peculiar humour. The work was put into rehearsal soon after the composer's return from Stettin, produced on April 29, 1827, and received with great apparent enthusiasm; but, for some reason which it is now impossible to ascertain, a cabal was formed against it, and it never reached a second performance. The critics abused it mercilessly; yet it exhibits merits of a very high order. The solemn passage for the trombones, which heralds the first appearance of the knight of La Mancha, is conceived in a spirit of reverent appreciation of the idea of Cervantes, which would have done honour to a composer of lifelong experience. Even the critics suborned to condemn the work could not refrain from expressing their admiration of this; but it had been decreed that the opera should not live—and it did not.

Mendelssohn was excessively annoyed at this injustice, and some time elapsed before his mind recovered its usual bright tone; but he continued to work diligently for the cause of art. Among other serious undertakings he formed a choir for the study of the great choral works of Sebastian Bach, then entirely unknown to the public; and, in spite of Zelter's determined opposition, he succeeded, in 1829, in inducing the Berlin Singakademie to give a public performance of the *Passion according to St Matthew*, under his direction, with a chorus of between three and four hundred voices. The scheme succeeded beyond his warmest hope, and proved the means of restoring to the world great compositions with which we are all now familiar, but which at that time had never been heard since the death of Bach. But the obstructive party were grievously offended; and at this period Mendelssohn was far from popular among the musicians of Berlin.

In April 1829 Mendelssohn paid his first visit to London. His reception was most enthusiastic. He made his first appearance before an English audience at one of the Philharmonic Society's concerts—then held in the Argyll Rooms—on the 25th of May, conducting his symphony in C minor from the pianoforte, to which he was led by John Cramer. On the 30th he played Weber's *Concertstück* from memory, a proceeding at that time extremely unusual. At a concert given by Drouet on the 24th of June he played Beethoven's pianoforte concerto in E flat, which had never before been heard in the country; and the overture to *A Midsummer Night's Dream* was also, for the first time, presented to a London audience. On returning home from the concert Mr Attwood, then organist of St Paul's Cathedral, left the score of the overture in a hackney coach, whereupon Mendelssohn wrote out another from memory without an error. At another concert he played with Moscheles his still unpublished concerto in E for two pianofortes and orchestra. After the close of the London season he started with Klingemann on a tour through Scotland, where he was inspired with the first idea of his overture to *The Isles of Fingal*, returning to Berlin at the end of November. Except for an accident to his knee, which lamed him for some considerable time, his visit was a highly successful one, and laid the foundation of many firm friendships and many prosperous negotiations in the time to come.

The visit to England formed in reality the first division only of a great scheme of travel which his father wished him to extend to all the most important art centres in Europe. After refusing the offer of a professorship at Berlin, he started again in May 1830 for Italy, pausing on his way at Weimar, where he spent a memorable fortnight with Goethe, and reaching Rome, after many pleasant interruptions, on November 1. No possible form of excitement ever prevented him from devoting a certain time every day to composition; but he lost no opportunity of studying either the countless treasures which form the chief glory of the great city or the manners and customs of modern Romans He attended, with insatiable curiosity, the services in the Sistine Chapel, and his keen power of observation enabled him to throw much interesting light upon them His letters on this subject, however, lose much of their value through his incapacity to comprehend the close relation existing between the music of Palestrina and his contemporaries and the ritual of the Roman Church His Lutheran education kept him in ignorance even of the first principles of ordinary chanting, and it is amusing to find him describing as enormities peculiar to the papal choir customs familiar to every village singer in England, and as closely connected with the structure of the "Anglican chant as with that of "Gregorian music Still, though he could not agree, in all points, with Baini, the greatest ecclesiastical musician then living, he fully shared his admiration for the *Improperia*, the *Miserere*, and the *cantus planus* of the *Lamentations* and the *Exultet*, the musical beauty of which he could understand, apart from their ritual significance

---

[1] After Mendelssohn's death this house was sold to the Prussian Government, and the Herrenhaus now stands on the site of the garden house.

In passing through Munich on his return in October 1831, he composed and played his pianoforte concerto in G minor, and accepted a commission (never fulfilled) to compose an opera for the Munich theatre Pausing for a time at Stuttgart, Frankfort and Dusseldorf, he arrived in Paris in December, and passed four pleasant months in the renewal of acquaintances formed in 1825, and in close intercourse with Liszt and Chopin On February 19, 1832, the overture to *A Midsummer Night's Dream* was played at the conservatoire, and many of his other compositions were brought before the public, but he did not altogether escape disappointments with regard to some of them, especially the Reformation symphony, and the visit was brought to a premature close in March by an attack of cholera, from which, however he rapidly recovered

On the 23d of April 1832 he was again in London, where he twice played his G minor concerto at the Philharmonic concerts gave a performance on the organ at St Paul's, and published his first book of *Lieder ohne Worte* He returned to Berlin in July, and during the winter he gave public performances of his Reformation symphony, his concerto in G minor, and his *Walpurgisnacht* In the following spring he paid a third visit to London for the purpose of conducting his Italian symphony, which was played for the first time by the Philharmonic Society, on the 13th of May 1833 On the 26th of the same month he conducted the performances at the Lower Rhine festival at Dusseldorf, with such brilliant effect that he was at once invited to accept the appointment of general music director to the town, an office which included the management of the music in the principal churches, at the theatre, and at the rooms of two musical associations This post he willingly accepted, and it formed a stepping stone to a far more important one

Before entering upon his new duties, Mendelssohn paid a fourth visit to London, with his father, returning to Dusseldorf on the 27th of September 1833 His influence produced an excellent effect upon the church music and in the concert-room but his relations with the management of the theatre were not altogether pleasant and it was probably this circumstance which first led him to forsake the cultivation of the opera for that of sacred music At Dusseldorf he first designed his famous oratorio *St Paul*, in response to an application from the Cacilien Verein at Frankfort, composed his overture to *Die schone Melusine*, and planned some other works of importance He liked his appointment, and would probably have retained it much longer had he not been invited to undertake the permanent direction of the Gewandhaus concerts at Leipsic, and thus raised to the highest position attainable in the German musical world To this new sphere of labour he removed in August 1835, opening the first concert at the Gewandhaus, on the 4th of October, with his overture *Die Meeresstille*, a work possessing great attractions, though by no means on a level with the *Midsummer Night's Dream*, *The Isles of Fingal*, or *Melusine*

Mendelssohn's reception in Leipsic was most enthusiastic, and under their new director the Gewandhaus concerts prospered exceedingly Meanwhile *St Paul* steadily progressed, and was first produced, with triumphant success, at the Lower Rhine festival at Dusseldorf, on May 22, 1836 On October 3 it was first sung in English, at Liverpool, under the direction of Sir George Smart, and on March 16, 1837, Mendelssohn again directed it at Leipsic

The next great event in Mendelssohn's life was his happy marriage, on March 28, 1837, to Cecile Charlotte Sophie Jeanrenaud, whose amiable disposition, surpassing beauty, and indescribable charm of manner endeared her to all who knew her The honeymoon was scarcely over before he was again summoned to England to conduct *St Paul*, at the Birmingham festival, on September 20th During this visit he played on the organ at St Paul's and at Christ Church, Newgate Street, with an effect which exercised a lasting influence upon English organists It was here also that he first contemplated the production of his second oratorio, *Elijah*

Passing over the composition of the *Lobgesang* in 1840, a sixth visit to England in the same year, the scheme for the erection of a monument to Sebastian Bach, and other events on which space does not permit us to enlarge, we find Mendelssohn in 1841 recalled to Berlin by the king of Prussia, with the title of Kapellmeister Though this appointment resulted in the production of *Antigone*, *Œdipus Coloneus*, *Athalie*, the incidental music to the *Midsummer Night's Dream*, and other great works, it proved an endless source of vexation, and certainly helped to shorten the composer's life In 1842 he came to England for the seventh time, accompanied by his wife, conducted his Scotch symphony at the Philharmonic, again played the organ at St Peter's, Cornhill, and Christ Church, Newgate Street, and was received with all possible honour by the queen and the prince consort He did not, however, permit his new engagements to interfere with the direction of the Gewandhaus concerts, and in 1843 he founded in Leipsic the great conservatoire which soon became the best musical college in Europe, opening it on April 3, in the buildings of the Gewandhaus In 1844 he conducted six of the Philharmonic concerts in London, producing his new *Midsummer Night's Dream* music, and playing Beethoven's pianoforte concerto in G with extraordinary effect He returned to his duties at Berlin in September, but happily succeeded in persuading the king to free him from his most onerous engagements, and his delight at this relief was unbounded

After a brief residence in Frankfort, Mendelssohn returned to Leipsic in September 1845, resuming his old duties at the Gewandhaus, and teaching regularly in the conservatoire Here he remained, with little interruption, during the winter,—introducing his friend Jenny Lind, then at the height of her popularity, to the critical frequenters of the Gewandhaus, and steadily working at *Elijah*, the first performance of which he conducted at the Birmingham festival, on August 26, 1846 The enthusiastic reception of this great work is well known Unhappily, the excitement attendant upon its production, added to the irritating effect of the worries at Berlin, made a serious inroad upon the composer's health On his return to Leipsic he worked on as usual, but it was clear that his health was seriously impaired. In 1847 he visited England for the tenth and last time, to conduct four performances of *Elijah* at Exeter Hall, on the 16th, 23d, 28th, and 30th of April, one at Manchester on the 20th, and one at Birmingham on the 27th. Again the queen and prince consort received him with marked respect,—one might almost venture to say, affection,—and all seemed prosperous and happy. But the necessary exertion was far beyond his strength. He witnessed Jenny Lind's first appearance at Her Majesty's Theatre, on the 4th of May, and left England on the 9th, little anticipating the trial that awaited him in the tidings of the sudden death of his sister Fanny, which reached him only a few days after his arrival in Frankfort. The loss of his mother in 1842 had shaken him much, but the suddenness with which this last sad intelligence was communicated broke him down completely. He fell to the ground insensible, and never fully recovered. In June he was so far himself again that he was able to travel, with his family, by short stages, to Interlaken, where he stayed for some time, illustrating the journey by a series of water-colour drawings, but making no attempt at composition for many weeks. He returned to Leipsic in September, bringing with him fragments of *Christus*, *Loreley*, and some other unfinished works, taking no part in the concerts, and living in the strictest privacy. On the 9th of October he called on Madame Frege, and asked her to sing his latest set of songs. She left the room for lights, and on her return found him in violent pain and almost insensible. It was the beginning of the end. He lingered on, now better, now worse, through four weary weeks, and on the 4th of November he passed away, in the presence of his wife, his brother, and his three dear friends, Moscheles, Schleinitz, and Ferdinand David. A cross now marks the site of his grave, in the Alte Dreifaltigkeits Kirchhof, at Berlin.

Mendelssohn's title to a place among the greatest composers of the century is incontestable. His style, though differing but little in technical arrangement from that of his classical predecessors, is characterized by a vein of melody peculiarly his own, and easily distinguishable by those who have studied his works not only from the genuine effusions of contemporary writers but from the most successful of the servile imitations with which, even during his lifetime, the music shops were deluged. In less judicious hands the rigid symmetry of his phrasing might perhaps have palled upon the ear; but under his skilful management it serves only to impart an additional charm to thoughts which derive their chief beauty from the evident spontaneity of their conception. In this, as in all other matters of a purely technical character, he regarded the accepted laws of art as the medium by which he might most certainly attain the ends dictated by the inspiration of his genius. Though caring nothing for rules except as means for producing a good effect, he scarcely ever violated them, and was never weary of impressing their value upon the minds of his pupils. His method of counterpoint was modelled in close accordance with that practised by Sebastian Bach. This he used in combination with an elastic development of the sonata form similar to that engrafted by Beethoven upon the lines laid down by Haydn. The principles involved in this arrangement were strictly conservative; yet they enabled him, at the very outset of his career, to invent a new style, no less original than that of Schubert or Weber, and no less remarkable as the embodiment of canons already consecrated by classical authority than as a special manifestation of individual genius. It is thus that Mendelssohn stands before us as at the same time a champion of conservatism and an apostle of progress; and it is chiefly by virtue of these two apparently incongruous though really perfectly compatible phases of his artistic character that his influence and example have for so many years held in check the violence of reactionary opinion which a little injudicious encouragement might easily have fanned into revolutionary fury. Happily this wholesome influence is still at work among us; and in his oratorios, his symphonies, his overtures, his concertos, and his smaller pianoforte pieces Mendelssohn has left us an example the value of which is universally recognized, and not likely to be soon forgotten.

Concerning Mendelssohn's private character there have never been two opinions. As a man of the world he was more than ordinarily accomplished—brilliant in conversation, and in his lighter moments overflowing with sparkling humour and ready pleasantry, loyal and unselfish in the more serious business of life, and never weary of working for the general good. As a friend he was unvaryingly kind, sympathetic, and as true as steel. His earnestness as a Christian needs no stronger testimony than that afforded by his own delineation of the character of St Paul; but it is not too much to say that his heart and life were pure as those of a little child.

A complete list of Mendelssohn's published compositions—one hundred and nineteen in number, besides some five and twenty unnumbered works of considerable importance—will be found in the thematic catalogue published by Messrs Breitkopf and Härtel at Leipsic, and also in Grove's *Dictionary of Music and Musicians*, vol. ii. pp. 308-310. Among his miscellaneous writings may be mentioned a translation [illegible]

collection of lett[illegible]

a far closer acqua[illegible]

to conv[illegible]

MENDELSSOHN, Moses (1729-1786), philosopher and scholar, well known as Lessing's friend and the prototype of his "Nathan," was born on September 6, 1729, at Dessau on the Elbe, where his Jewish father made a scanty livelihood by teaching a small school and transcribing copies of the "law." The leading events of Mendelssohn's career have been indicated elsewhere (see JEWS, vol. xiii. p. 680). His numerous writings include *Ueber Evidenz in metaphysischen Wissenschaften* (1763), which gained the prize in a competition in which Immanuel Kant took part; *Briefe über die Empfindungen* (1764); *Phädon oder über die Unsterblichkeit der Seele* (1767), an argument for immortality, founded on the nature of the soul as exempting it from the ordinary laws of change, which has been severely criticized by Kant; *Jerusalem, oder über religiöse Macht und Judenthum* (1783), a specially important contribution to the question of Jewish emancipation; a number of contributions to his friend Nicolai's *Litteraturbriefen* and *Bibliothek der schönen Wissenschaften*; one or two tracts in Hebrew; and some new German translations from the Old Testament. The controversy which led to the publication of his *Morgenstunden* (1785-86), a reply to Jacobi's *Briefe über die Lehre Spinozas*, is said to have been more or less directly the cause of his death, which took place on January 4, 1786 (see JACOBI, vol. xiii. p. 537). Of Mendelssohn's three sons, the second, Abraham, settled as a banker in Hamburg, and married a Jewess, Lea Salomon Bartholdy, who bore him four children; these, by advice of their mother's brother, himself a conscientious convert from Judaism, were educated as Christians, and thenceforth joined their mother's second surname to their own. The second of them, Felix, is the subject of the preceding notice. In later life Abraham Mendelssohn was accustomed to say:—"When I was young I was the son of my father; now I am the father of my son." See *The Mendelssohn Family*, 1882.

MENDOZA, a city of the Argentine Republic, the only town of the province of Mendoza, lies 700 miles west-north-west of Buenos Ayres, at the foot of the Cordilleras, 2510 feet above the sea-level, in 32° 53′ S. lat. and 68° 49′ W. long. It was formerly a frequent stopping-place on the route across the Andes by the Uspallata Pass, and used to rank as one of the best built towns in the country; but in 1861 it was almost completely destroyed by an appalling earthquake, in which the people, for the most part collected in the churches, perished to the number of about 12,000. Bravard, a French geologist who had often predicted the catastrophe, was one of those who perished. Extensive ruins still mark the site of the old town; the new town, which has been built at a little distance, has grown rapidly. Situated in a richly cultivated district, Mendoza depends mainly on agriculture and fruit-growing.

The city was founded in [illegible] by [illegible], and in 1776 it was made the administrative centre of the viceroyalty of La Plata. See Mulhall, *Handbook to the River Plate*, 1875; and Mrs Mulhall, *Between the Amazon and the Andes*, 1882.

MENDOZA, Diego Hurtado de (1503-1575), novelist, poet, diplomatist, and historian, was a younger son of the member of the illustrious Mendoza family to whom the government of Granada was entrusted not long after its surrender, and was born in that city about the year 1503 The marquis of Santillana, so prominent a figure at the court of John II of Castile, was his great grandfather At an early age Mendoza, who had been destined for the church, was sent to Salamanca, where he studied with success, and also, some time between the years 1520 and 1525, produced his *Lazarillo de Tormes*, the work upon which his literary celebrity largely rests Having persuaded his father to allow him to enter the army, he served with the Spanish troops of Charles V in Italy, and also availed himself of opportunities as they arose to hear the lectures of famous professors at Bologna, Padua, and Rome In 1538 he was taken into the diplomatic service of the emperor and sent as ambassador to Venice there he cultivated friendly relations with the Aldi, and energetically set about collecting a library not only procuring copies of many old MSS in the public library of the city, but also sending to Thessaly and Mount Athos for new ones it was from his collection that the complete text of Josephus was first printed For some time he held the post of military governor of Siena, and, after having been present in an official capacity in Trent at the beginning of the œcumenical council, he was in 1547 sent as special plenipotentiary to Rome, where he continued to act for some years In 1554, shortly before the abdication of Charles, he was recalled to Spain and his official career came to an end He was never a favourite with Philip II , and in consequence of a quarrel with a courtier, in which he had lost his temper badly, he was finally banished from court in 1568 The remaining years of his life, which were spent at Granada, he devoted partly to the study of Arabic, partly to poetical composition, and partly to the preparation of his history of the Moorish insurrection of 1568–70 (*Guerra de Granada*) He died at Madrid (which he had obtained leave to visit on some business errand) in April 1575

Mendoza's *Lazarillo de Tormes*, though written during his college days was not published until 1553, when it was printed anonymously at Antwerp Next year it was reprinted at Burgos but ultimately it was taken exception to by the Inquisition, and the Spanish editions of 1573 and subsequent years are accordingly considerably abridged It is a comparatively short fragment written in vigorous and bright Castilian and was the first example in modern literature of the ' novela picaresca of which Le Sage's *Gil Blas* now ranks as the most perfect specimen The continuations first by an anonymous author (1555) and afterwards by H de Luna (1620) are of very inferior interest Of Mendoza as a poet all that need be said here is that he followed the modern Italian models quite as far as was compatible with a due regard to his Castilian individuality His history though of no great bulk is like his novel a work of remarkable literary execution It relates indeed only to a comparatively brief episode in a chapter of events for which it is almost impossible to claim much general attention, and it is often needlessly erudite and sometimes provokingly obscure But as a whole it is singularly well informed, dignified, and picturesque, "the style is bold and abrupt but true to the idiom of the language and the current of thought is deep and strong easily carrying the reader onward with its flood Nothing in the old chronicling style of the earlier period is to be compared to it and little in any subsequent period is equal to it for manliness vigour and truth (Ticknor) The first edition of the *Guerra de Granada* did not appear until 1610 but was even then incomplete the first perfect edition was that of 1730 The work has frequently been reprinted since

MENDOZA, IÑIGO LOPEZ DE See SANTILLANA

MENELAUS, king of Sparta, was the brother of AGAMEMNON (*q v*) and the husband of HELENA (*q v*) He was one of the heroes of the Trojan horse, and recovered his wife at the sack of the city On the voyage homewards his fleet was scattered off Malea by a storm which drove him to Crete, after seven years further wandering to Cyprus, Phœnicia, Egypt, Ethiopia, Libya, and the country of the Erembi, he at last had an interview with Proteus and obtained a favourable wind which brought him home on the very day on which Orestes was holding the funeral feast over Ægisthus and Clytæmnestra After a long and happy life in Lacedæmon, Menelaus, as the son in law of Zeus, did not die but was translated to Elysium

MENGS, ANTONY RAPHAEL (1728–1779), was the most celebrated representative of the eclectic school of painting in the 18th century, and played a great part in the early days of the classic revival He was born in 1728 at Aussig in Bohemia, but his father, a Danish painter, established himself finally at Dresden, whence in 1741 he conducted his son to Rome Mengs early showed that active intelligence and large capacity for laborious study which secured him the extraordinary distinction which he enjoyed through life His appointment in 1749 as first painter to the elector of Saxony did not prevent his spending much time in Rome, where he had married in 1748, and abjured the Protestant faith, and where he became in 1754 director of the Vatican school of painting, nor did this hinder him on two occasions from obeying the call of Charles III of Spain to Madrid There Mengs produced some of his best work, and specially the ceiling of the banqueting hall, the subject of which was the Triumph of Trajan and the Temple of Glory After the completion of this work in 1777, Mengs again returned to Rome, and there he died, two years later, in poor circumstances, leaving twenty children, seven of whom were pensioned by the king of Spain Besides numerous paintings in the Madrid gallery, the Ascension at Dresden, Perseus and Andromeda at St Petersburg, and the ceiling of the Villa Albani must be mentioned among his chief works In England, the duke of Northumberland possesses a Holy Family, and the colleges of All Souls and Magdalen, at Oxford, have altar pieces by his hand In his writings, in Spanish, Italian, and German, Mengs has put forth his eclectic theory of art, which treats of perfection as attainable by a well schemed combination of diverse excellences,—Greek design, with the expression of Raphael, the chiaroscuro of Correggio, and the colour of Titian His close intimacy with Winkelmann—who constantly wrote at his dictation—has greatly enhanced his historical importance, for he formed no scholars, and the critic must now concur in Goethe's judgment of Mengs in *Winkelmann und seine Jahrhundert*, he must deplore that so much learning should have been allied to a total want of initiative and utter poverty of invention, and embodied with a strained and artificial mannerism

See *Opere di Antonio Raffaello Mengs* Parma 1780, *Mengs' Werke, uebersetzt v G F Prange* 1786 *Zeitschrift fur bildende Kunst*, 1880, Bianconi, *Elogio Storico di Mengs*, Milan 1780, Nagler's *Kunstlerlexikon*

MENHADEN, economically one of the most important fishes of the United States, known by a great number of local names, "menhaden" and "mossbunker" being those most generally in use In systematic works it appears under the names of *Clupea menhaden* and *Brevoortia tyrannus* It is allied to the European species of shad and pilchard, and, like the latter, approaches the coast in its wanderings in immense shoals, which are found throughout the year in some part of the littoral waters between Maine and Florida, the northern shoals retiring into deeper water or to more southern latitudes with the approach of cold weather The average size of the menhaden is about 12 inches Although it was long known as a palatable table-fish, and largely used, when salted, for export to the West Indies, and as bait for cod and mackerel, the menhaden fishery has been developed to its present importance only within the last twenty years A large fleet of steamers and sailing vessels is engaged in it, and a great number of large factories have sprung into existence to extract the oil, which is used for tanning and currying, and for adulterating other more expensive oils, and to manufacture the refuse into a very valuable guano In the year 1877 2,426,589 gallons of oil and 55,444 tons of guano were produced.

An extensive business is also carried on in converting menhaden of a suitable size into "American sardines."

A very complete account of this fishery is given by G. Brown Goode in "The Natural and Economic History of the American Menhaden," *United States Commission of Fish and Fisheries*, part v., Washington, 1879.

MENIN, a small Belgian town, in the province of West Flanders, it is traversed by the river Lys, which there forms the boundary between France and Belgium. The population in 1880 was 10,200. Commercially and industrially Menin ranks high for its size, possessing, as it does, important manufactures of linen, oil, soap, &c., as well as sugar refineries, breweries, and tanneries, and a good corn and cattle market. Tobacco is extensively grown in the neighbourhood, and forms one of the main items of lawful trade, a good deal of illicit traffic also being carried on across the French frontier.

Menin does not appear to have been in any way worthy of note until the 14th century. Philip II. caused it to be fortified in 1578. It was taken by Turenne in 1658. Vauban subsequently surrounded it with elaborate works, and made it one of the strongest citadels in France, but all its fortifications were razed in 1744. It belonged to the Netherlands in 1815 and became part of Belgium in 1830.

MENINGITIS (from *μῆνιγξ*, a membrane), a term in medicine applied to inflammation affecting the membranes of the brain (cerebral meningitis) or spinal cord (spinal meningitis) or both.

Of *cerebral meningitis* there are two varieties:—(1) that due to the presence of tubercle in the membranes of the brain, which gives rise to the disease known as tubercular meningitis, or acute hydrocephalus; and (2) simple or acute meningitis, which may arise from various causes. Among the more common are injuries of the head, extension of disease from contiguous parts, such as erysipelas of the scalp or caries of the bones of the ear, exposure to cold or to extreme heat, the presence of tumours in the substance of the brain. It may likewise occur in the course of fevers, rheumatism, and inflammatory affections, and also as a result of mental overwork, sleeplessness, and alcoholic excess. This latter variety of meningitis is less common than the former, but it is on the whole more amenable to treatment. The symptoms present such a general resemblance to those already described in tubercular meningitis that it is unnecessary to refer to them in detail (see HYDROCEPHALUS), and the treatment is essentially the same for both.

Spinal meningitis, or inflammation of the membranes investing the spinal cord, generally results from causes of a similar kind to those producing cerebral meningitis,—injuries, exposure to cold or sudden changes of temperature, diseases affecting adjacent parts such as the vertebral column or the spinal cord itself, or extension downwards of inflammation of the membranes of the brain. It is said to be most common in males. As in the case of the brain, the membranes become extremely congested; exudation of lymph and effusion of serum follow, and the spinal cord and roots of the nerves become more or less involved in the morbid process.

The chief symptoms are fever, with severe pain in the back or loins shooting downwards into the limbs (which are the seat of frequent painful involuntary startings), accompanied with a feeling of tightness round the body. The local symptoms bear reference to the portion of the cord the membranes of which are involved. Thus when the inflammation is located in the cervical portion the muscles of the arms and chest are spasmodically contracted, and there may be difficulty of swallowing or breathing, or embarrassed heart's action, while when the disease is seated in the lower portion, the lower limbs and the bladder and rectum are the parts affected in this way. At first there is excited sensibility (hyperæsthesia) in the parts of the surface of the body in relation with the portion of cord affected. As the disease advances these symptoms give place to those of partial loss of power in the affected muscles, and also partial anæsthesia. These various phenomena may entirely pass away, and the patient after some weeks or months recover; or, on the other hand, they may increase, and end in permanent paralysis.

The treatment is directed to allaying the pain and inflammatory action by opiates. Ergot of rye is strongly recommended by many physicians. The patient should have perfect rest in the recumbent, or better still in the prone, position. Cold applications to the spine may be of use, while scrupulous attention to the functions of the bladder and bowels, and to the condition of the skin with the view of preventing bed sores, is all important.

Epidemic Cerebro-spinal Meningitis.—This name, as well as *cerebro-spinal fever*, is applied to a disease defined in the *Nomenclature of Diseases* as "a malignant epidemic fever, attended by painful contractions of the muscles of the neck and retraction of the head. In certain epidemics it is frequently accompanied by a profuse purpuric eruption, and occasionally by secondary effusions into certain joints. Lesions of the brain and spinal cord are found on dissection." This disease appears to have been first distinctly recognized in the year 1837, when it prevailed as an epidemic in the south-west of France, chiefly among troops in garrison. For several years subsequently it existed in various other localities in France, and mostly among soldiers. At the same time in other countries in western and central Europe the disease was observed in epidemic outbreaks both among civil and military populations. In 1846 it first showed itself in Ireland, chiefly among the inmates of workhouses in Belfast and Dublin. Numerous outbreaks occurred also about the same period in many parts of the United States. In more recent times the disease has repeatedly appeared both in Europe and America, but it has seldom prevailed extensively in any one tract of country, the outbreaks affecting for the most part limited communities, such as garrisons or camps, schools, workhouses, and prisons.

Little is known regarding the causation of this disease. All ages seem liable to suffer; and, as regards sex, males are affected more commonly than females. Occupation and condition of life appear to exercise no influence. It has been observed to occur most frequently in cold seasons. The question of the contagiousness of cerebro-spinal fever remains still unsettled, but the weight of authority appears to be in favour of the theory of the communicability of the disease. It cannot, however, be regarded as contagious in the same degree as some other specific fevers, such as typhus fever, small-pox, or scarlatina.

The following are the more prominent symptoms. After a few days of general discomfort the attack comes on sharply with rigors, intense headache, giddiness, and vomiting. Neuralgic pains in the abdomen, and pain with spasmodic contractions in the muscles of the extremities, occur at an early stage. The headache continues with great severity, and restlessness and delirium supervene, accompanied with periods of somnolence. The pains and spasms rapidly increase, the muscles of the neck, spine, and limbs being specially affected. The patient's head is drawn backwards and rigidly fixed, the spine arched, and the arms and legs powerfully flexed, the whole condition bearing a considerable resemblance to tetanus. For a time there is greatly increased sensibility of the skin, pain being excited by the slightest contact. There is more or less fever present. About the fourth day of the disease an eruption on the skin both of the face and body frequently appears in the form either of purpuric spots or small clear vesicles. Death may take place in from a few hours to eight or ten days. Should the patient survive the immediate shock of the attack, serious complications are apt to appear in the form of destructive inflammation of the eyes or ears, inflammation with effusion into certain joints, and paralysis of limbs; or, again, recovery may take place after a prolonged convalescence. The mortality appears to vary in different epidemics, in some being as high as 80 per cent., in others only about 20 per cent. Certain forms of the disease are of malignant character from the first, and very rapidly fatal.

The changes found after death in cerebro-spinal fever are intense inflammation of the membranes of the brain and spinal cord, with effusion of serum or pus into the ventricular and arachnoid spaces.

The treatment is similar to that of other febrile conditions; but for the special symptoms of pain, spasm, &c., opium seems to have been found of eminent service, while quinine and ergot of rye are also recommended.

MENNONITES is a name borne by certain Christian communities in Europe and America, denoting their adherence to a type of doctrine of which Menno Simons was, not indeed the originator, but the chief exponent at the time when the anti-pædo-baptism of the congregations in which he laboured took permanent form in opposition to ordinary Protestantism on the one hand and to the theocratic ideas of the Munster type of anabaptism on the other. The original home of the views afterwards called Mennonite was in Zurich, where, as early as 1525, Grebel and Manz founded a community having for its most distinctive mark baptism upon confession of faith. The chief doctrines of these Zurich Baptists have been already stated in the article BAPTISTS, vol. iii. p. 353. The main interest of the sect lay not in dogma but in discipline. Within the communities evangelical life was reduced to a law of separation from the world, and this separation—enforced by a stringent use of excommunication and the prohibition of marriage beyond the brotherhood—involved not only abstinence from worldly vanities but refusal of civic duties (the state being held to be un-Christian)—refusal to take an oath or use the sword. In their revolt against the corruptions of the mediæval church the Reformers neither denied the continuity of the church as an organization nor impugned the Christian character of the state. The new sect did both, and their position thus appeared so radically subversive of the foundations of society that it is not surprising under the imperfect views of toleration then current, that they became the objects of bitter persecution from Protestants as well as from Catholics. But the Grebelians had no desire, like the fanatics of Munster, to found a new theocracy in opposition to the anti-Christian state. They sought only to withdraw from what their conscience condemned, content to live as strangers upon earth, and devoting all their energy to preserve the purity of their own communities. The mediæval conception of separation from the world as the true path of Christian perfection had leavened all middle-class society in Europe, and prepared many to accept separatist views of the church as soon as they were reached by the impulse of revolt against Roman Catholicism; the pursuit of holiness in a society protected by a strict discipline is an idea which experience has shown to have a great attraction for one class of earnest minds; hence, in spite of persecutions incomparably fiercer than any of the larger Protestant bodies ever underwent, the new doctrine and praxis rapidly spread from Switzerland to Germany, Holland, and even to France. Each community was quite independent, united to the rest only by a bond of love. There was no sort of hierarchy, but only 'exhorters' chosen by the congregation, of whom the most prominent were also "elders" entrusted with the administration of the sacraments—an organization so easily kept alive or reproduced that the movement could hardly be checked by any persecution short of the total annihilation which at length was actually the fate of many of the Swiss communities. The remnants of the Swiss Mennonites broke in 1620 into two parties, the stricter of which, the Ammanites or Upland Mennonites, were distinguished from the Lowland Mennonites by holding that excommunication of one party dissolved marriage, and by their rejection of buttons and the use of the razor. Their persecution lasted till 1710; a few congregations still remain and keep themselves quite distinct from Baptist bodies of more modern origin. In Germany the Mennonites are somewhat more numerous; more important are the German Mennonite colonies in southern Russia, brought thither in 1783 by the empress Catherine, which in turn have recently sent many emigrants to America. America indeed, and especially Pennsylvania, early became a refuge for the Mennonites of Switzerland, the Palatinate, and Holland, and is now the chief home of the body (175,000 in the United States and 25,000 in Canada). The oldest congregation is that of Germantown (since 1683); the most numerous of several divisions are the Old Mennonites, corresponding to the less strict of the Swiss sections.

All these communities in Europe and America are distinguished by an antique simplicity combined with antique prejudices, by indifference to the interests of the greater world, while at the same time their industry and self-concentration have made them generally well-to-do. Their religious type has varied very little in the course of centuries, as indeed is not surprising, their theology being ascetic rather than dogmatic or speculative. The Mennonites of Holland, on the other hand, have passed through an interesting and progressive history.

It was in Holland and the adjoining parts of Low Germany that the personal influence of Menno Simons (1492–1559) was mainly felt. He was originally a priest, and was pastor at his native place Witmarsum in Friesland from 1531 to 1536, when convictions long ripening in his mind compelled him to resign his cure. At this time the anti-pædo-baptist societies in the Low Countries were much agitated. The views which had just before received their political death-blow at Munster (see ANABAPTISTS) were not extinct, and even those who did not share them were by no means at one. Menno attached himself to the Obbenites, who held that on earth true Christians had no prospect but to suffer persecution, refused to use the sword, and looked for no millennium on earth. Menno became one of their elders, and by his wanderings among the scattered and oppressed communities, and especially by the natural eloquence and religious power of his numerous writings, did much to sustain the faith of his associates, to confirm the type of their religious life, and to prevent startling aberrations in doctrine or discipline. He was not an original thinker, but the love which all felt for the man, and which was kept alive for generations by his writings, gave him the place which the name of Mennonites expresses.

It may be ascribed to the influence of Menno's writings that the Dutch Mennonites, though for a time (since 1554) they broke into fractions on questions of discipline, and especially on the effect of excommunication upon marriage, never fell so far apart as regards the type of their religious life as to preclude the possibility of reunion. The Waterlanders in North Holland, who held the least strict doctrine of excommunication, soon moved farther in the direction of liberality, and exchanged the name Mennonites for that of Doopsgezinden (baptist persuasion). In 1579 they refused to condemn any one for opinions, even on the incarnation, which the word of Scripture did not pronounce necessary to salvation. They aided William the Silent with money, and from 1581 to 1618 even accepted civil office. Meantime the stricter party had undergone various divisions, which, however, in 1627–32 were reunited on the basis of confessions essentially embodying Menno's teachings. They too had learned moderation, at least in their views of excommunication, and their antithesis to the state was softened since the cessation of persecution in 1581, but especially since in 1672 they were recognized as citizens. On the other hand, the adoption of a confession had deepened the separation between them and the liberal Doopsgezinden; but doctrine was never the fundamental principle of the Mennonite communities, confessionalism took no firm root, and the two sections gradually approached, and through a series of partial fusions became at length finally united when the Amsterdam congregations came together in 1801. The persuasion declined much in numbers in the 18th century; since then it has increased, and has now 127 congregations with nearly 50 000 members. The objection to hold civil office disappeared in 1795, that to carry arms in the war of freedom against Napoleon. Baptism on profession of faith and the refusal of the oath, tolerance in matters of doctrine without religious indifference, are the chief marks of the body, which in point of theological culture and general enlightenment, philanthropic zeal and social importance, has long stood very high.

Authorities.—The best life of Menno Simons is Cramer's (1837). De Hoop Scheffer's article in Herzog-Hauck, *R. E.*, is excellent; only one point of consequence in his account seems to call for modification—the book against John of Leyden said to have been published before Menno joined the Obbenites is almost certainly spurious. See Sepp, *Geschiedkundige Nasporingen*, i. (1872), p. 178 *sq.* The completest edition of Menno's works is that in folio, 1681. Many of them are known only in bad Dutch versions; Menno himself wrote in the Oostersch or East Sea Dialect of Low German. For the literature on the Mennonites in general see De Hoop Scheffer, on whom the foregoing sketch is mainly dependent.

MENSHIKOFF, ALEXANDER DANILOVICH (1672–1729), born at Moscow on the 17th of November (O.S.) 1672, was the son of a poor man, who employed him to sell cakes about the streets of that city. In this humble occupation he attracted the attention of Lefort, one of Peter the Great's most active co-operators, who was pleased with his sprightliness, and took him into his service. Peter, soon afterwards seeing the youth at Lefort's, was also delighted with him, and took him to be his page Menshikoff soon became indispensable to the czar, assisting him in his workshop, and displaying signal bravery in the company of his master at the siege of Azoff He formed one of the suite of Peter during his travels, and worked with him at Saardam and Deptford Throughout his wars with the Swedes, Menshikoff was the companion of the czar, and greatly distinguished himself For his gallantry at the battle of the Neva, on the 7th of May (o s) 1703, he received the order of St Andrew In 1704 he was made general, and at the request of the czar created a prince of the Holy Roman Empire His house on the Vasilii Ostroff was magnificent, there ambassadors were received, and banquets were given gorgeous with gold and silver plate Unfortunately there is a dark side to the picture, and the favourite was guilty of extortion to such an extent as to bring him under his master's censure On the death of Peter the position of Menshikoff became very perilous, his successes had raised about him a host of enemies eager for his downfall The Golitzins, Dolgoroukis, and all those who formed what may be called the Old Russian party, wished to proclaim the son of Alexis emperor Those, however, whose aggrandizement was bound up with Peter's reforms—Menshikoff, Apraksin, Bontourlin, Goloffkin, and others—were in favour of giving the crown to Peter's widow, who accordingly ascended the throne as Catherine I During her reign the influence of Menshikoff was unbounded, and he virtually governed the country, but the empress died in 1727, after a reign of two years She had made a will, no doubt at the instigation of the favourite, to the effect that Peter, her grandson, was to be czar under the guardianship of Menshikoff, whose daughter Mary was to be married to the youthful sovereign Under pretence of taking care of the young czar, Menshikoff caused him to be removed to his house and surrounded him with his creatures He was now at the height of his power, foreign ambassadors remarked that even the great Peter himself was never feared so much The young czar, however, showed no affection for Mary Menshikoff, and the girl was equally apathetic towards her betrothed, being in love with a member of the family of Sapieha at the time her father had forced her into the engagement The Dolgoroukis used the aversion of the young prince to his *fiancee* as a means of creating dislike to the father A chain of events was gradually leading to the downfall of the favourite He was soon refused admittance to the summer palace, whither the young czar had retired Next he was arrested, and so overpowered was he at his disgrace that he had an apoplectic stroke In vain did he address letters both to the emperor and his sister Shortly after, by order of the czar, the fallen magnate departed from St Petersburg, but more like a nobleman retiring to his estate than a culprit going into exile The people regarded him with dislike, and most of them rejoiced over his fall On his way a courier arrived with orders to take the czar's ring of betrothal from his daughter Mary and give her back her own, which had been worn by Peter II Menshikoff was not permitted to pass through Moscow, but was conducted to Oranienburg, in the government of Riazan, and there placed under strict surveillance Soon afterwards the whole family was banished to Siberia, and arrived at Berezoff towards the end of 1727 Menshikoff's wife died on the journey, and was buried near Kazan On the arrival of the prisoners they were lodged in a wooden house, consisting of four rooms But Menshikoff did not long endure the horrors of exile in this inclement region According to Mannstein, he died (November 12, o s, 1729) of an apoplectic stroke, because there was no one at Berezoff, as he himself remarked, who understood how to open a vein The young czar ordered the release from exile of the two remaining children of Menshikoff,—his daughter Mary had died at Berezoff in the same year as her father,—and restored some of their property to them

MENSHIKOFF, Alexander Sergeievich (1787–1869), great grandson of Peter's favourite, born in 1787, entered the Russian service as attache to the embassy at Vienna He accompanied the emperor Alexander throughout his campaigns against Napoleon, and attained the rank of general but retired from active service in 1823 He then devoted himself to naval matters, and put the Russian marine which had fallen into decay during the reign of Alexander on an efficient footing On the outbreak of the Crimean War he was appointed commander in chief, and suffered a severe defeat at the Alma On the death of the emperor Nicholas in 1855 he was recalled, ostensibly on account of failing health He died in 1869

MENSURATION

MENSURATION, or the art of measuring, involves the construction of measures, the methods of using them, and the investigation of rules by which magnitudes which it may be difficult or impossible to measure directly are calculated from the ascertained value of some associated magnitude It is usual, however, to employ the term mensuration in the last of these senses and we may therefore define it to be that department of mathematical science by which the various dimensions of bodies are calculated from the simplest possible measurements

The determination of the lengths and directions of straight lines, including what are familiarly known as problems in heights and distances, generally depends on the solution of triangles, and will be discussed in the articles Trigonometry and Surveying The remaining portions of the subject are the determinations of the lengths of curves, the areas of plane or other figures, and the volumes and surfaces of solids and it is of mensuration as thus restricted that the present article will discuss some of the more important problems

§ 1 *Units of Length, Area, and Volume* – In measuring any magnitude we select some standard or "unit" to measure by Thus in measuring length we take for unit an inch, a foot, or a yard From the unit of length we derive the units of area and volume Thus we define the unit of area to be the area of the square described upon the unit of length, and the unit of volume to be the volume of the cube whose edge is the unit of length or whose side is the unit of area For example, if an inch be taken as the unit of length, the square whose side is 1 inch is the unit of area, and the cube whose edge is 1 inch is the unit of volume The length of a line, the area of a surface and the volume of a solid are then expressed by the numbers, whole or fractional, of units of length area, and volume which they respectively contain Hence, if l denote the linear unit, the length of a line which contains a units is al, or simply a since l is unity similarly the area of a surface which contains b units of area is bm, or simply b where m is the unit of area

§ 2 *Commensurable and Incommensurable Magnitudes* — When two magnitudes have a common measure, that is, when another magnitude can be found which is contained in each an exact number of times, they are said to be "commensurable" Thus a line $4\frac{1}{2}$ and another $3\frac{1}{4}$ inches long are commensurable, for, if $\frac{1}{2}$ inch be taken as unit of length, the former contains the unit nine times and the latter seven times If no common measure can be found, the two magnitudes are said to be "incommensurable" For instance, 1 and $\sqrt{2}$ have no common measure, for $\sqrt{2}=1.4142$ an interminable decimal, and hence no unit, however small, can be found which will be contained in each an exact number of times If, however, we take $\sqrt{2}=1.4$, the error will be less than $\frac{1}{10}$ if $\sqrt{2}=1.414$, the error will be less than $\frac{1}{1000}$ &c Hence, by taking a sufficient number of figures, we can find a fraction which will differ from $\sqrt{2}$ by less than any assignable quantity, and therefore we can always find two commensurable magnitudes that will represent two incommensurable ones to any degree of accuracy we please In what follows we need therefore only consider commensurable lines

§ 3 *Area of a Rectangle* —Let the side AB (fig 1) contain a units and the side BC b units of length If we divide AB into a equal parts, each equal to the unit of length, and similarly BC into b equal parts, and if through the points of division we draw lines parallel to the sides of the rectangle these lines will divide the rectangle into a series of rectangles, each of which is the unit of area, since each is a square whose sides are of unit length As we have a rows of these rectangles, and b in each row, the whole number of rectangles will be ab Therefore

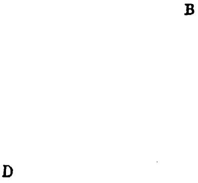


Fig 1

$$\text{area of ABCD} = ab \text{ units of area}$$
$$= ab$$

PART I —PLANE FIGURES

SECTION I —PLANE FIGURES CONTAINED BY STRAIGHT LINES

A *The Rectangle*

§ 4 Let ABCD (fig 2) be a rectangle and let AB=CD=a, BC=DA=b, AC=c, and the angle BAC=α, it is required to find its area Since a rectangle is completely determined when two independent data one of which at least is a length are given connecting its parts we can determine its area in the following cases

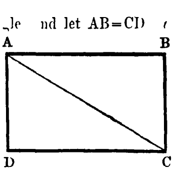


Fig 2

(a) *When its length* a *and its breadth* b *are given* —It has already been proved (§ 3) that

$$\text{area of ABCD} = ab$$

or the area of a rectangle is equal to its length multiplied by its breadth

Example —Let $a=12$ feet 6 inches and $b=9$ inches, then

$$\text{area of ABCD} = 12.5 \times .75 = 9.375 \text{ square feet}$$

If we make use of logarithms in the above calculation we have

$$\log \text{area} = \log a + \log b$$
$$\log a = \log 12.5 = 1.0969100$$
$$\log b = \log .75 = 1.8750613$$

therefore $\log \text{area} = .9719713$,

hence $\text{area} = 9.375$

(β) *When a side* a *and the diagonal* c *are given* —By Euclid i 47 we have

$$b^2 = c^2 - a^2, \text{ or } b = \sqrt{c^2 - a^2},$$

therefore $\text{area of ABCD} = ab = a\sqrt{c^2 - a^2}$,

or $\log \text{area} = \log a + \frac{1}{2}\log(c+a) + \frac{1}{2}\log(c-a)$

Example —Let $a=238$ and $c=456$ then

$$\log a = \log 238 = 2.3765770$$
$$\tfrac{1}{2}\log(c+a) = \tfrac{1}{2}\log 694 = 1.4206797$$
$$\tfrac{1}{2}\log(c-a) = \tfrac{1}{2}\log 218 = 1.1692282$$

therefore $\log \text{area} = 4.9664849$,

hence $\text{area} = 92573.1$

(γ) *When a side* a *and its inclination to the diagonal are given* —Since

$$\frac{b}{a} = \tan\alpha, \quad b = a\tan\alpha,$$

and therefore $\text{area of ABCD} = ab = a^2\tan\alpha$,

or $\log \text{area} = 2\log a + \text{L}\tan\alpha - 10$

Example —Let $a=36$ and $\alpha = 32°\ 25'\ 15''$, then

$$2\log a = 2\log 36 = 3.1126050$$
$$\text{L}\tan\alpha = \text{L}\tan 32°\ 25'\ 15'' = 9.8028622$$

therefore $\log \text{area} = 12.9154672 - 10 = 2.9154672$,

hence $\text{area} = 823.127$

(δ) *When the diagonal* c *and* α *its inclination to either of the sides are given* —We have

$$a = c\cos\alpha, \text{ and } b = c\sin\alpha,$$

therefore $\text{area of ABCD} = ab = c^2\sin\alpha\cos\alpha = \frac{1}{2}c^2\sin 2\alpha$,

or $2\text{area} = c^2\sin 2\alpha$,

and hence $\log 2\text{area} = 2\log c + \text{L}\sin 2\alpha - 10$

§ 5 A square being a rectangle whose sides are equal, we can at once determine its area When one datum, which must be a length, is given the square is completely determined, and hence we have only two cases to consider

(a) *When the side is given* —From § 4, a, we have at once

$$\text{area of square} = ab = a \times a = a^2$$

(β) *When the diagonal* c *is given* —From § 4, β, we have

$$a^2 + a^2 = c^2, \text{ or } a^2 = \tfrac{1}{2}c^2,$$

hence $\text{area of square} = a^2 = \frac{1}{2}c^2$, or $2\text{area} = c^2$,

and therefore $\log 2\text{area} = 2\log c$

B *Right angled Triangles*

§ 6 The diagonal of every rectangle divides it into two equivalent right angled triangles (Eucl i 34) and hence the area of the right angled triangle ABC (fig 2) is equal to half the area of the corresponding rectangle ABCD

C *Triangles Generally*

In every triangle there are six elements to be considered, namely the three sides and the three angles If any three of these six be given, provided one is a length the triangle is completely determined and hence its area can be found

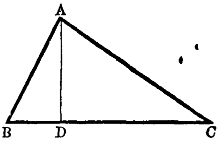


Fig 3

§ 8 *Length of Perpendiculars of a Triangle* —In the triangle ABC (fig 3) let BC=a, CA=b, AB=c, AD the perpendicular from A on BC=h, BD=x, and CD=y

Since BDA and CDA are right angles, we have

$$c^2 = x^2 + h^2, \text{ and } b^2 = y^2 + h^2,$$

and therefore

$$b^2 - c^2 = y^2 - x^2 = (y+x)(y-x) = a(y-x),$$

whence

$$y - x = \frac{b^2 - c^2}{a}$$

But $y + x = a$, and, by solving these equations we obtain

$$\frac{b^2 + a^2 - c^2}{2a}$$

$$= b^2 - y^2 = b^2 - \left(\frac{b^2+a^2-c^2}{2a}\right)^2 = \frac{(2ab)^2 - (b^2+a^2-c^2)^2}{4a^2}$$

$$= \frac{(a+b+c)(b+c-a)(c+a-b)(a+b-c)}{4a^2}$$

hence

$$h = \frac{1}{2a}\sqrt{(a+b+c)(b+c-a)(c+a-b)(a+b-c)}$$

Now let $a+b+c=2s$, then $b+c-a=2(s-a)$, $c+a-b=2(s-b)$, and $a+b-c=2(s-c)$

Therefore, on substituting and reducing, we obtain

Similarly the perpendiculars from B and C on the opposite sides are respectively

$$\frac{2}{b}\sqrt{s(s-a)(s-b)(s-c)}, \text{ and } \frac{2}{c}\sqrt{s(s-a)(s-b)(s-c)}$$

§ 9 We now proceed to investigate formulæ for the area of a triangle in the following important cases

(a) *When the base* a *and the altitude* h *are given* —Since a triangle is equal to half a rectangle of the same base and altitude, we have at once

$$\text{area ABC} = \tfrac{1}{2}ah$$

Example.—Let $a = 40$ chains and $h = 14.52$ chains, then

$$\text{area} = \tfrac{1}{2} \times 40 \times 14.52 = 290.4 \text{ square chains}$$

(β) *When two sides* a *and* c *and the included angle* B *are given*.—From fig. 3 $\frac{h}{c} = \sin B$, and therefore $h = c \sin B$,

hence $$\text{area} = \tfrac{1}{2}ah = \tfrac{1}{2}ac \sin B\,,$$

or $$\log 2\,\text{area} = \log a + \log c + \text{L}\sin B - 10$$

Example.—Let $a = 40$, $c = 30$, and $B = 30°$, then

$$\text{area} = \tfrac{1}{2}ac \sin B = \tfrac{1}{2} \times 40 \times 30 \times \tfrac{1}{2} = 300$$

(γ) *When the three sides* a, b, c *are given*.—From § 8

$$h = \frac{2}{a}\sqrt{s(s-a)(s-b)(s-c)}\,,$$

and therefore

$$\text{area} = \tfrac{1}{2}ah = \tfrac{1}{2}a \times \frac{2}{a}\sqrt{s(s-a)(s-b)(s-c)} = \sqrt{s(s-a)(s-b)(s-c)}\,;$$

or $$\log \text{area} = \tfrac{1}{2}\{\log s + \log(s-a) + \log(s-b) + \log(s-c)\}$$

Since $2s = a + b + c$, we have

$$\text{area of triangle} = \tfrac{1}{4}\sqrt{2(a^2b^2 + b^2c^2 + c^2a^2) - (a^4 + b^4 + c^4)}\,.$$

Example 1.—Let $a = 13$, $b = 14$, and $c = 15$, then

$$s = \tfrac{1}{2}(13 + 14 + 15) = 21\,,\quad s - a = 21 - 13 = 8\,,$$
$$s - b = 21 - 14 = 7\,,\ \text{and}\ s - c = 21 - 15 = 6\,,$$

therefore $$\text{area} = \sqrt{21 \times 8 \times 7 \times 6} = 84$$

Example 2.—Let $a = 255$, $b = 238$, and $c = 221$, then

$$\begin{aligned}
\log s &= \log 357 = 2.5526682\\
\log(s-a) &= \log 102 = 2.0086002\\
\log(s-b) &= \log 119 = 2.0755470\\
\log(s-c) &= \log 136 = \underline{2.1335389}
\end{aligned}$$

therefore $$\log \text{area} = \tfrac{1}{2}(8.7703543) = 4.3851771\,,$$

hence $$\text{area} = 24276$$

(δ) *When any two angles* B *and* C *and the adjacent side* a *are given*.—Since

$$\frac{c}{a} = \frac{\sin C}{\sin A}\,,\quad c = \frac{a \sin C}{\sin A}\,,$$

and therefore (by β)

$$\text{area} = \tfrac{1}{2}ac \sin B = \frac{a^2 \sin B \sin C}{2 \sin A}\,,\quad \text{where } A = 180° - (B + C),$$

or $$\log 2\,\text{area} = 2\log a + \text{L}\sin B + \text{L}\sin C + \text{L}\operatorname{cosec} A - 30$$

Since all the angles of a triangle are given when any two are given, we can find the area of a triangle when any two angles and any one side are given. Thus, when A, B, and *c* are given, we know C also, and the problem reduces to a case of the preceding.

(ε) *When the three medians* α, β, γ *are given*.—If *a*, *b*, *c* be the three sides of a triangle, and α, β, γ the three medians, *i.e.*, the lines drawn from the angles to the middle points of the opposite sides, then by well known geometrical propositions we have

$$4(\alpha^2 + \beta^2 + \gamma^2) = 3(a^2 + b^2 + c^2)\,,$$
$$16(\alpha^2\beta^2 + \beta^2\gamma^2 + \gamma^2\alpha^2) = 9(a^2b^2 + b^2c^2 + c^2a^2)\,,$$

and $$16(\alpha^4 + \beta^4 + \gamma^4) = 9(a^4 + b^4 + c^4)$$

Now (§ 9, γ)

$$\text{area of triangle} = \tfrac{1}{4}\sqrt{2(a^2b^2 + b^2c^2 + c^2a^2) - (a^4 + b^4 + c^4)}\,,$$

therefore $$= \tfrac{1}{3}\sqrt{2(\alpha^2\beta^2 + \beta^2\gamma^2 + \gamma^2\alpha^2) - (\alpha^4 + \beta^4 + \gamma^4)}\,.$$

D. *Parallelograms*

§ 10. The opposite sides and angles of a parallelogram being equal, three independent data, one of which at least is a length, are necessary and sufficient to determine it completely.

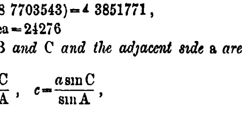


Fig. 4

In the parallelogram ABCD (fig. 4) let $BC = DA = a$, $AB = CD = b$, $AC = c$, $AE = h$, the angle $ABC = \alpha$ and $AOD = \beta$.

Since the diagonal AC divides the parallelogram into two equivalent triangles, we obtain

(α) $$\begin{aligned}\text{area of ABCD} &= 2 \text{ area of triangle ABC}\\ &= 2 \times \tfrac{1}{2}\, a \times h \ (\S\ 9,\ \alpha) = ah\,,\end{aligned}$$

(β) $$\text{area of ABCD} = 2 \text{ area ABC} = 2 \times \tfrac{1}{2}ab \sin\alpha \ (\S\ 9,\ \beta) = ab \sin\alpha\,,$$

or $$\log \text{area} = \log a + \log b + \text{L}\sin\alpha - 10\,,$$

(γ) $$\text{area of ABCD} = 2 \text{ area ABC} = 2(\text{ABO} + \text{CBO})$$
$$= 2\{\tfrac{1}{2}\text{BO}\cdot\text{AO}\sin\text{AOB} + \tfrac{1}{2}\text{BO}\cdot\text{CO}\sin\text{COB}\} = 2\{\tfrac{1}{2}\text{BO}\cdot\text{AC}\sin\beta\}$$
$$= \tfrac{1}{2}\text{BD}\cdot\text{AC}\sin\beta = \tfrac{1}{2}cd \sin\beta\,,$$
$$\log 2\,\text{area} = \log c + \log d + \text{L}\sin\beta - 10$$

§ 11. If the parallelogram be *equiangular* (a rectangle), $c = d$, and area $= \tfrac{1}{2}c^2 \sin\beta$. If it be *equilateral* (a rhombus), $\beta = 90°$, and area $= \tfrac{1}{2}cd$. If it be both *equiangular* and *equilateral* (a square), $c = d$ and $\beta = 90°$, and area $= \tfrac{1}{2}c^2$ as before (§ 5, β).

E. *Trapeziums*

§ 12. To determine a trapezium completely four data are necessary and sufficient.

In the trapezium ABCD (fig. 5) let $BC = a$, $CD = b$, $DA = c$, $AB = d$,

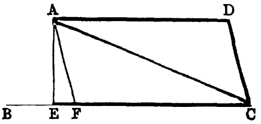


Fig. 5

and AE perpendicular to $BC = h$, and draw AF parallel to CD, then

(α) $$\begin{aligned}\text{area ABCD} &= \text{area ABC} + \text{area ADC}\\ &= \tfrac{1}{2}ah + \tfrac{1}{2}ch\\ &= \tfrac{1}{2}(a + c)h\,,\end{aligned}$$

or the area is equal to *half the sum of the parallel sides multiplied by the perpendicular between them*.

Again, area of $\text{ABF} = \tfrac{1}{2}\text{BF} \times \text{AE}\ (\S\ 9,\ \alpha) = \tfrac{1}{2}(a - c)h$,

also $$\text{area of ABF} = \sqrt{s(s - \text{AB})(s - \text{BF})(s - \text{FA})}\,,$$

where $$2s = \text{AB} + \text{BF} + \text{FA}\,,$$

hence $$h = \frac{2}{a - c}\sqrt{s(s - \text{AB})(s - \text{BF})(s - \text{FA})},\ \text{therefore}$$

(β) $$\text{area of ABCD} = \tfrac{1}{2}(a + c)h = \frac{a + c}{a - c}\sqrt{s(s - \text{AB})(s - \text{BF})(s - \text{FA})}$$
$$= \tfrac{1}{4}\frac{a + c}{a - c}\sqrt{(-a + b + c + d)(a + b - c - d)(a + b - c + d)(a - b - c + d)}$$

since $$\text{AB} = d\,,\ \text{BF} = a - c\,,\ \text{and FA} = \text{CD} = b$$

Thus we can find the area of a trapezium in terms of its sides.

§ 13. If $c = 0$, ABCD becomes a triangle, and its area

$$= \tfrac{1}{4}\sqrt{(-a + b + d)(a + b - d)(a + b + d)(a - b + d)}$$

Again, if $c = a$, then also $b = d$, and ABCD becomes a parallelogram, and its area takes the indeterminate form $\frac{0}{0}$, as it should do, since four sides do not completely determine a parallelogram.

F. *Quadrilaterals Generally*

§ 14. A quadrilateral is completely determined when five independent data are given. We consider the following cases.

(α) *When any diagonal and the perpendiculars on it from the opposite vertices are given.*

$$\begin{aligned}\text{The quadrilateral ABCD (fig. 6)} &= \text{ABD} + \text{BCD}\\ &= \tfrac{1}{2}\text{BD}\cdot\text{AE} + \tfrac{1}{2}\text{BD}\cdot\text{CF}\\ &= \tfrac{1}{2}\text{BD}(\text{AE} + \text{CF})\,,\end{aligned}$$

or the area is equal to half the product of the diagonal and the sum of the perpendiculars.

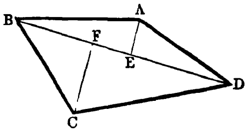


Fig. 6

If the diagonal BD fall without the figure, as in the concave quadrilateral ABCD (fig. 7), then it is clear that

$$\text{area ABCD} = \tfrac{1}{2}\text{BD}(\text{AE} - \text{CF}).$$

(β) *When the diagonals and their included angle are given.*—In the quadrilateral ABCD (fig. 8, p. 16) let $\text{BD} = h$, $\text{AC} = k$, and angle $\text{DEA} = \alpha$, then

$$\begin{aligned}\text{ABCD} &= \text{ABD} + \text{BCD}\\ &= \tfrac{1}{2}\text{BD}\cdot\text{AE}\sin\alpha + \tfrac{1}{2}\text{BD}\cdot\text{CE}\sin\alpha\ (\S\ 10,\ \gamma)\\ &= \tfrac{1}{2}h(\text{AE} + \text{CE})\sin\alpha\\ &= \tfrac{1}{2}hk \sin\alpha\,,\end{aligned}$$

or the area is equal to the product of the diagonals and the sine of their contained angle.

The same result holds when one of the diagonals falls without the quadrilateral, as in fig. 7, as the reader can easily verify.

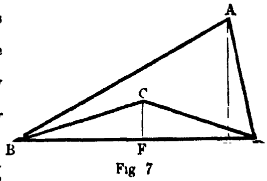


Fig. 7

(γ) *When the four sides and the angle between the diagonals are given.*—If *a*, *b*, *c*, *d* be the sides and α the angle between the diagonals it can easily be shown that

$$\text{area of quadrilateral} = \tfrac{1}{4}(a^2 - b^2 + c^2 - d^2)\tan\alpha.$$

(δ) *When the four sides are given and the opposite angles are supplementary*—In fig 8 let $AB=a$, $BC=b$, $CD=c$, $DA=d$, $AC=h$, angle $ABC=\alpha$, angle $CDA=\beta$, and let $\alpha+\beta=180°$, then

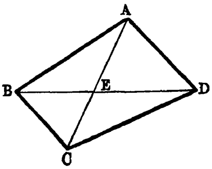


Fig 8

$$\text{area of ABCD}=\text{ABC}+\text{ADC}$$
$$=\tfrac{1}{2}ab\sin\alpha+\tfrac{1}{2}cd\sin\beta$$

But

$$\sin\beta=\sin(180°-\alpha)=\sin\alpha,$$

therefore

$$\text{area of ABCD}=\tfrac{1}{2}(ab+cd)\sin\alpha$$

This gives us the area of the quadrilateral in terms of the four sides and one angle

Again we have

$$a^2+b^2-2ab\cos\alpha=h^2=c^2+d^2-2cd\cos\beta=c^2+d^2+2cd\cos\alpha$$

therefore $\cos\alpha=\dfrac{a^2+b^2-c^2-d^2}{2(ab+cd)}$, and hence

$$1+\cos\alpha=\frac{(a+b+c-d)(a+b-c+d)}{2(ab+cd)}$$

$$1-\cos\alpha=\frac{(c+d+a-b)(c+d-a+b)}{2(ab+cd)}$$

From this we obtain

$$\sin^2\alpha=(1+\cos\alpha)(1-\cos\alpha)$$
$$=\frac{(b+c+d-a)(c+d+a-b)(d+a+b-c)(a+b+c-d)}{4(ab+cd)}$$

Now let $a+b+c+d=2s$,

then $\tfrac{1}{2}(ab+cd)\sin\alpha=\sqrt{(s-a)(s-b)(s-c)(s-d)}$,

therefore $\text{area of ABCD}=\sqrt{(s-a)(s-b)(s-c)(s-d)}$,

or $\log\text{area}=\tfrac{1}{2}\{\log(s-a)+\log(s-b)+\log(s-c)+\log(s-d)\}$

If $d=0$ the quadrilateral becomes a triangle, and its area is $\sqrt{(s-a)(s-b)(s-c)s}$ as before In extracting the square root of $\sin\alpha$ we take the positive sign since the angle α is less than two right angles

G *Regular Polygons*

§ 15 Since a regular polygon is both equilateral and equiangular, a circle can be inscribed within it and also described about it, and thus the n straight lines drawn from the common centre of the two circles to the n vertices of the polygon divide it into n triangles equal in every respect Therefore the area of the polygon is equal to n times the area of any one of these triangles

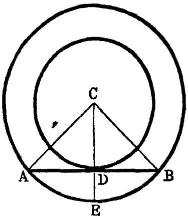


Fig 9

§ 16 *Radius of Inscribed and Circumscribed Circles*—Let AB (fig 9) $=a$ be a side of a regular polygon of n sides let C be the centre of the inscribed and circumscribed circles, $CD=r$ the radius of the former and $CF=R$ the radius of the latter The angle ACB is evidently equal to the nth part of four right angles, that is

$$ACB=\frac{360°}{n},\ \text{and}\ ACD=\tfrac{1}{2}ACB=\frac{180°}{n}$$

Now $AD=\dfrac{a}{2}=CD\tan ACD=r\tan\dfrac{180°}{n}$

and $AD=\dfrac{a}{2}=AC\sin ACD=R\sin\dfrac{180°}{}$

therefore

and

§ 17 *Perimeter of Polygon*—The perimeter of the polygon of n sides is na i e, $2nr\tan\dfrac{180°}{n}$, or $2nR\sin\dfrac{180°}{n}$

From this it follows that the perimeters of the inscribed and circumscribed regular polygons of n sides of a circle of radius r are

$$2nr\sin\frac{180°}{n}\ \text{and}\ 2nr\tan\frac{180°}{n}\ \text{respectively}$$

§ 18 *Area of Polygon*

(α) *In terms of* r—The area of polygon

$$=n\,ACB=n\,AD\cdot CD=n\times r^2\tan\frac{180°}{},$$

(β) *In terms of* R—The triangle ACB

$$=\tfrac{1}{2}AC\cdot CB\sin ACB=\tfrac{1}{2}R^2\sin\frac{360°}{n},$$

and therefore area of polygon $=\tfrac{1}{2}nR^2\sin\dfrac{360°}{n}$

(γ) *In terms of* a—The triangle ACB

$$=\tfrac{1}{2}AB\cdot CD=\frac{a}{2}\times r=\frac{a}{2}\times\tfrac{1}{2}a\cot\frac{180°}{n}=\frac{a^2}{4}\cot\frac{180°}{n},$$

and therefore area of polygon $=a^2\times\dfrac{n}{4}\cot\dfrac{180°}{n}$,

$$\log 4\,\text{area}=\log n+L\cot\frac{180°}{n}+2\log a-10$$

From α and β it follows that the areas of the inscribed and circumscribed regular polygons of n sides of a circle of radius r are

$$\tfrac{1}{2}nr^2\sin\frac{360°}{n}\ \text{and}\ nr\tan\frac{180°}{n}\ \text{respectively}$$

§ 19 In the formula (§ 18, γ) for the area of a polygon, the factor $\dfrac{n}{4}\cot\dfrac{180°}{n}$ has a definite value for every value of n, and hence, if we find its value once for all for a large number of values of n, and tabulate the results, we can find the area of a regular polygon of n sides by multiplying the square of its side by the appropriate tabular value

Again, if $a=1$ we have

$$r=\tfrac{1}{2}\cot\frac{180°}{n}\ \text{and}\ R=\tfrac{1}{2}\operatorname{cosec}\frac{180°}{n}$$

and thus we obtain in a similar manner the radius of the inscribed and circumscribed circles by multiplying the side by the appropriate tabular value of $\tfrac{1}{2}\cot\dfrac{180°}{n}$ and $\tfrac{1}{2}\operatorname{cosec}\dfrac{180°}{n}$ respectively

§ 20 The following table contains the values of $\dfrac{n}{4}\cot\dfrac{180°}{n}$ and their logarithms, and the values of $\tfrac{1}{2}\cot\dfrac{180°}{n}$ and $\tfrac{1}{2}\operatorname{cosec}\dfrac{180°}{n}$ for all values of n from 3 to 12

n	$\frac{n}{4}\cot\frac{180}{n}$	Logarithms	$\frac{1}{2}\cot\frac{180}{n}$	$\frac{1}{2}\operatorname{cosec}\frac{180°}{n}$
3	0 433012	$\bar{1}$ 6365006	0 28867	57735
4	1 0000000	0 0000000	0 5000	70710
5	1 7204774	0 2356490	0 68819	85065
6	2 5980762	0 4146519	0 86602	1 0000
7	3 6339124	0 5603745	1 0383	1 1523
8	4 8284271	0 6380568	1 2071	1 3065
9	6 1818242	0 7911166	1 3737	1 4619
10	7 6942088	0 8861640	1 5388	1 6180
11	9 3656407	0 971537	1 7028	1 7747
12	11 1961524	1 0490688	1 8660	1 9318

Let A denote the area of a polygon of n sides and A′ the corresponding tabular value of $\dfrac{n}{4}\cot\dfrac{180°}{n}$, then

$$A=a^2A',$$
$$\log A=2\log a+\log A'$$

H—*Length of the Radius of the Inscribed, Escribed, and Circumscribed Circles of a Triangle*

§ 21 (α) *Radius of Inscribed Circle*—Let O (fig 10) be the centre of the circle inscribed in the triangle ABC and touching the sides in D, E and F Join OA, OB and OC The angles at D, E, F are right angles (Eucl iii 18) Let $BC=a$, $CA=b$, $AB=c$, and $OD=OE=OF=r$

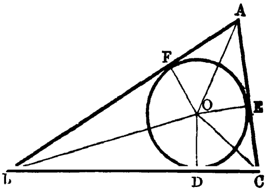


Fig 10

Now $ABC=BOC+COA+AOB$

$$=\tfrac{1}{2}ar+\tfrac{1}{2}br+\tfrac{1}{2}cr=\tfrac{1}{2}(a+b+c)r=rs,$$

whence $r=\dfrac{\text{area of ABC}}{}=\dfrac{\sqrt{s(s-a)(s-b)(s-c)}}{}$

(β) *Radius of Escribed Circles*—Let $OD=OE=OF=r_a$, then

$$ABC=ACO+ABO-BOC$$
$$=\tfrac{1}{2}br_a+\tfrac{1}{2}cr_a-\tfrac{1}{2}ar_a=\tfrac{1}{2}(b+c-a)r_a=r_a(s-a),$$

and $r_a=\dfrac{\text{area of ABC}}{s-a}=\dfrac{\sqrt{s(s-a)(s-b)(s-c)}}{s-a}=\sqrt{\dfrac{s(s-b)(s-c)}{s-a}}$.

Similarly

$$r_b=\sqrt{\frac{s(s-a)(s-c)}{s-b}}\ \text{and}\ r_c=\sqrt{\frac{s(s-a)(s-b)}{s-c}}.$$

(γ) *Radius of Circumscribed Circle*.—Let AD (fig. 12)=p the perpendicular from A on the side BC, and AE=2R the diameter

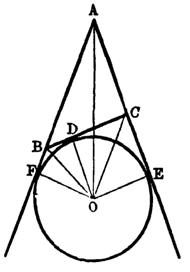


Fig. 11

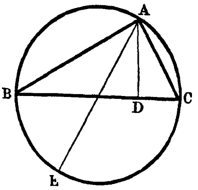


Fig. 12

of the circle, then (Eucl. vi. C) we have

$$2R\times p=b\times c,$$

therefore $$2R\times ap=abc.$$

Now $ap=2\Delta$, where Δ denotes the area of ABC,

hence $$R=\frac{abc}{4\Delta}=\frac{abc}{4\sqrt{s(s-a)(s-b)(s-c)}}.$$

Example.—Let $a=13$, $b=14$, and $c=15$; then r will be found to be 4, r_a 10½, r_b 12, r_c 14 and R 8⅛.

SECTION II.—PLANE FIGURES CONTAINED BY CURVED LINES.

A. The Circle.

§ 22. *Circumference of a Circle*.—If we inscribe in any circle a regular polygon of n sides, and also circumscribe a regular polygon of the same number of sides, it is clear that the perimeter of the circle is intermediate between the perimeters of the inscribed and circumscribed polygons, and that the difference between the perimeters of the inscribed and circumscribed polygons can be made as small as we please by sufficiently increasing n. A similar statement holds with reference to the areas of the circle and the inscribed and circumscribed polygons. With the above assumptions it is easily proved that the circumference of a circle bears a constant ratio to its diameter. Hence we have

Circumference = C = constant × radius = constant × r.

It is usual to denote this constant by 2π, and therefore

$C=2\pi r=\pi d$, where d is the diameter of the circle.

§ 23. *Numerical Value of* π.—The constant π being, as can be easily proved, an interminable decimal, we can only approximate to its value, but this we can do to any degree of accuracy we please.

If s and σ denote respectively a side of the inscribed and circumscribed polygons of n sides, and s' and σ' a side of the inscribed and circumscribed polygons of $2n$ sides, it can easily be shown that

$$(\alpha)\ \sigma=\frac{rs}{\sqrt{r^2-(\tfrac{1}{2}s)^2}},\qquad (\beta)\ s'^2=2r\left\{r-\sqrt{r^2-(\tfrac{1}{2}s)^2}\right\},$$

$$(\gamma)\ \sigma'=\frac{rs'}{\sqrt{r^2-(\tfrac{1}{2}s')^2}},$$

where r is the radius of the circle.

If we take $r=\frac{1}{2}$ we find, by means of these formulæ, and by assuming the value of s when $n=6$, that the perimeter of inscribed polygon of 96 sides = 3·140 , and the perimeter of circumscribed polygon of 96 sides = 3·142.

From this we learn that the circumference of the circle, in this case π, is greater than 3·140 and less than 3·142 , and therefore as far as the second place of decimals

$$\pi=3\cdot 14.$$

By taking greater and greater values of n we obtain closer and closer approximations to π.

The preceding method for approximating to the value of π is the simplest afforded by elementary geometry, and is also the oldest, but better and more rapid methods are furnished by the higher mathematics. The calculation of π has been carried to 707 places of decimals, the following being the first 20 figures in the result:—

3·14159265358979323846.

For all practical purposes it is sufficient to take

$$\pi=3\cdot 14159 \text{ or } =\frac{355}{113}.$$

§ 24. The following table contains the functions of π that are of most frequent occurrence in mensuration:—

	Number	Logarithm		Number	Logarithm
π	3·1415927	0·4971499	π^2	9·8696044	0·9942997
2π	6·2831853	0·7981799			
4π	12·5663706	1·0992099	$\frac{1}{6\pi^2}$	0·0168869	$\bar{2}$·2275490
$\frac{1}{2}\pi$	1·5707963	0·1961199			
$\frac{1}{3}\pi$	1·0471976	0·0200286	$\sqrt{\pi}$	1·7724539	0·2485750
$\frac{1}{4}\pi$	0·7853982	$\bar{1}$·8950899			
$\frac{1}{6}\pi$	0·5235988	$\bar{1}$·7189986	$\sqrt[3]{\pi}$	1·4645919	0·1657166
$\frac{1}{8}\pi$	0·3926991	$\bar{1}$·5940599			
$\frac{1}{12}\pi$	0·2617994	$\bar{1}$·4179686	$\frac{1}{\sqrt{\pi}}$	0·5641896	$\bar{1}$·7514251
$\frac{4}{3}\pi$	4·1887902	0·6220886			
$\frac{\pi}{180}$	0·0174533	$\bar{2}$·2418774	$\frac{2}{\sqrt{\pi}}$	1·1283792	0·0524551
$\frac{1}{\pi}$	0·3183099	$\bar{1}$·5028501	$\frac{1}{2\sqrt{\pi}}$	0·2820948	$\bar{1}$·4503951
$\frac{4}{\pi}$	1·2732395	0·1049101	$\sqrt[3]{\frac{6}{\pi}}$	1·2407010	0·0936671
$\frac{1}{4\pi}$	0·0795775	$\bar{2}$·9007901	$\sqrt[3]{\frac{3}{4\pi}}$	0·6203500	$\bar{1}$·7926371
$\frac{180}{\pi}$	57·2957795	1·7581226	$\log_e\pi$	1·1447299	0·0586030

§ 25. *Units of Angular Measurement*.—In measuring lengths we select some line of constant length as the standard or unit; similarly in measuring angles we require to take some angle of constant magnitude as unit angle. The right angle is by its nature the simplest unit angle, but for convenience, we take the $\frac{1}{90}$th part of a right angle for unit, and call it a degree, which is subdivided into sixty equal parts called minutes and these again into sixty equal parts called seconds. For theoretical purposes we define the unit angle to be *the angle subtended at the centre of a circle by an arc equal to the radius*. This angle we call a "radian." In many treatises the radian measure of an angle is called the circular measure.

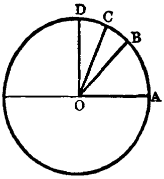


Fig. 13

§ 26. *The radian is a constant angle*.—Let OA (fig. 13)=arc AB =r, then AOB=radian, and let AOD=90°, then

$$\text{arc AD}=\tfrac{1}{4}\times 2\pi r=\tfrac{1}{2}\pi r,$$

and, since angles at the centre of a circle are proportional to the arcs on which they stand (Eucl. vi. 33),

$$\frac{\text{number of degrees in radian AOB}}{\text{number of degrees in AOD}}=\frac{\text{AB}}{\text{AD}}=\frac{r}{\frac{1}{2}\pi r}=\frac{2}{\pi};$$

therefore number of degrees in radian

$$=90^\circ\times\frac{2}{\pi}=57^\circ\cdot 2957795=\text{constant}.$$

§ 27. *Number of Radians in any Angle*.—Let AOC (fig. 13) be any angle, AOB the radian, and AC=s, then

$$\frac{\text{number of radians in AOC}}{\text{one radian}}=\frac{\text{AC}}{\text{AB}}=\frac{s}{r};$$

therefore number of radians in AOC $=\dfrac{s}{r}$.

If AOC=90°, then $s=\frac{1}{2}\pi r$, and number of radians $=\frac{1}{2}\pi$; there are thus π radians in two and 2π in four right angles.

When $r=1$ we have number of radians $=s$, and hence in some treatises for the number of radians in an angle we find the length of the arc given.

§ 28. *To transfer from degrees to radians and conversely*.—Let x denote the number of degrees in an angle and θ the number of radians in the same, then, since $\frac{\theta}{\pi}=\frac{x}{180^\circ}$,

$$(\alpha)\ \theta=\frac{\pi x^\circ}{180},\qquad(\beta)\ x^\circ=\frac{180}{\pi}\theta.$$

§ 29. The following table contains the values of θ for values of x up to 180°, and also for minutes and seconds.

Degrees	Radian	Degrees	Radian	Degrees	Radian	Minutes	Radian	Seconds	Radian ·000
1	·0174533	61	1·0646508	121	2·1118484	1	·0002909	1	0048
2	·0349066	62	1·0821041	122	2·1293017	2	·0005818	2	0097
3	·0523599	63	1·0995574	123	2·1467550	3	·0008727	3	145
4	·0698132	64	1·1170107	124	2·1642083	4	·0011636	4	0194
5	·0872665	65	1·1344640	125	2·1816616	5	·0014544	5	0242
6	·1047198	66	1·1519173	126	2·1991149	6	·0017453	6	0291
7	·1221730	67	1·1693706	127	2·2165682	7	·0020362	7	0339
8	·1396263	68	1·1868239	128	2·2340214	8	·0023271	8	0388
9	·1570796	69	1·2042772	129	2·2514747	9	·0026180	9	0436
10	·1745329	70	1·2217305	130	2·2689280	10	·0029089	10	0485
20	·3490659	80	1·3962634	140	2·4434610	20	·0058178	20	0970
30	·5235988	90	1·5707963	150	2·6179939	30	·0087266	30	1454
40	·6981317	100	1·7453293	160	2·7925268	40	·0116355	40	1939
50	·8726646	110	1·9198622	170	2·9670597	50	·0145444	50	2424
60	1·0471976	120	2·0943951	180	3·1415927	60	·0174533	60	2909

As an example of the use of this table we proceed to find th value of θ when $x=68° 45 17 8$

$$\begin{aligned}
\text{When } x&=68° & \theta&=1\ 1868239,\\
x&=40 & \theta&=\ \ 0116355,\\
x&=\ 5 & \theta&=\ \ 0014544,\\
x&=10 & \theta&=\ \ 0000485,\\
x&=\ 7 & \theta&=\ \ 0000339,\\
\text{and when } x&=0\ 8 & \theta&=\ \ \underline{0000039},\\
\text{therefore when } r&=68° 45\ 17\ 8 & \theta&=1\ 2000001
\end{aligned}$$

§ 30 Combining the results of §§ 27 and 28 we obtain

(a)

$$(\beta)\quad r=\frac{s}{\theta}=\frac{180}{\pi}\quad\frac{s}{x},$$

§ 31 *Length of Arcs of Circles* —The following are the more portant cases —

(a) *In terms of the chord of the arc and the radius of the circle* —Let AB (fig 14 $=2c$ AC$=r$ and AEB$=s$, then

AD$=\frac{1}{2}$AP$-$ $=r\sin\frac{1}{2}$C whence C is known, and therefore the arc s is found (§ 30 γ)

(β) *In terms of the height of the arc and the radius of the circle* —Let DE $=h=$ height of arc then

$$CD=CE-DE=r-h$$

and

$$\cos\tfrac{1}{2}C=\frac{CD}{AC}=\frac{r-h}{r},$$

whence C is found and therefore s

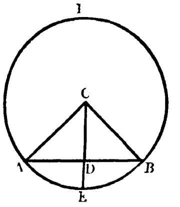


Fig 14

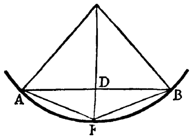


Fig 15

§ 32 *Huygens s Approximation to the Length of a Circular Arc* —Let AB (fig 15) $=p$ be the chord of the arc AEB, and AE$=$EB$=q$ that of half the arc then the arc AEB$=\frac{1}{3}(8q-p)$ approximately

For let r denote the radius s the arc AEB, and 2θ the angle ACB, then $\theta=\frac{s}{2r}$ Again AB$=p=2$AD$=2r\sin\theta=2r\sin\frac{s}{2r}$, and similarly $q=2r\sin\frac{s}{4r}$

Now

$$\sin\theta=\theta-\frac{\theta^3}{\underline{|3}}+\frac{\theta^5}{\underline{|5}}$$

therefore

$$p=2r\left\{\frac{s}{2r}\quad\frac{1}{\underline{|3}}\left(\frac{s}{2r}\right)^3+\frac{1}{\underline{|5}}\left(\frac{s}{2r}\right)^5-\&c\right\}$$

$$\overline{4\quad r}+\overline{2\quad 3\quad 4\quad 5\quad 16\quad r^4}$$

Similarly

$$8q=16r\left\{\frac{s}{4r}-\frac{1}{\underline{|3}}\left(\frac{s}{4r}\right)^3+\frac{1}{\underline{|5}}\left(\frac{s}{4r}\right)^5-\&c\right\}$$

$$=4s-\overline{2\quad 3\quad 4\quad r}+\overline{2\quad 3\quad 4\quad 5\quad 64\quad r^4}$$

Hence, neglecting powers of $\frac{s}{r}$ beyond the fourth we obtain

approximately

In practice it is sometimes more convenient to use the equivalent form

$$s=2q+\tfrac{1}{3}(2q-p)$$

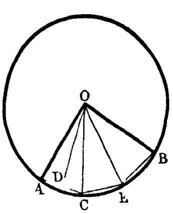


Fig 16

§ 33 *Area of Sector of a Circle* —Let the sector be OAB (fig 16) Divide the arc AB into n equal parts, and draw *the* chords of these Let P denote the perimeter of the broken line *AB, A* the area of the polygon AOB, and p the altitude of any one of the n equal triangles of which this polygon is made up

Now in the limit, when n is indefinitely increased, P becomes the arc AB$=s$, a result which we symbolize thus—

$$\mathrm{L}_{n=\infty}\,\mathrm{P}=\text{arc AB}=s$$

Similarly

$$\mathrm{L}_{n=\infty}\,p=\text{radius}=r$$

Again, the area of the sector is equal to the area of the polygon when the broken line AB becomes the arc AB, that is,

$$\text{sector}=\mathrm{L}_{n=\infty}\mathrm{A}=\mathrm{L}_{n=\infty}\tfrac{1}{2}p\times\mathrm{P}=\tfrac{1}{2}\mathrm{L}_{n=\infty}p\times\mathrm{L}_{n=\infty}\mathrm{P}$$
$$=\tfrac{1}{2}rs$$

§ 34 Let S denote the area of a sector of a circle, then, by means of the above result and § 27, we have

$$(\alpha)\quad S=\tfrac{1}{2}sr,$$
$$(\beta)\quad S=\tfrac{1}{2}r\theta\ \ r=\tfrac{1}{2}r^2\theta$$

§ 35 We proceed to find the area of a sector of a circle in the following additional cases —

(a) *When the chord of the sector and the radius of the circle are given* —In fig 14 let AB$=2c$, and let AC$=r$, then we have

$$\sin\frac{ACB}{2}=\frac{AD}{AC}=\frac{c}{r}$$

whence ACB and therefore θ is known, and S can be found by § 34

ACB has two values, the smaller one giving the area of the minor, and the larger that of the major conjugate sector

(β) *When the chord and height of the chord are given* —Let DE (fig 14) $=h$ and AB$=2c$, then

$$AC^2=r^2=AD^2+DC^2=c^2+(r-h)^2,\ \text{whence}$$

$r=\frac{c^2+h^2}{2h}$, and therefore by previous case the area can be found

(γ) *When the chord and angle subtended at the centre are given* —Let AB (fig 14) $=2c$ and ACB$=\theta$, then

$$\frac{c}{r}=\sin\frac{ACB}{2},\ \text{or } r=\frac{c}{\sin\frac{1}{2}\theta},$$

therefore area of sector $=\frac{1}{2}r^2\theta=\frac{1}{2}\left(\frac{c}{\sin\frac{1}{2}\theta}\right)^2\times\theta$

§ 36 *Area of a Circle* —The circle being a sector whose arc is the whole circumference we obtain at once

$$\text{area of circle}=\tfrac{1}{2}r\times s=\tfrac{1}{2}r\times 2\pi r=\pi r^2$$

An independent proof of this proposition might be given by means of the inscribed and circumscribed polygons, and from the area of a circle the area of a sector can be deduced The infinitesimal calculus affords a simple and elegant proof (see § 44)

§ 37 If A denote the area, r the radius, $d=2r$ the diameter, and C the circumference of a circle, we have

$$(\alpha)\quad A=\pi r^2,$$
$$(\beta)\quad A=\tfrac{1}{2}\times 2\pi r\times r=\tfrac{1}{2}Cr,$$
$$(\gamma)\quad A=\frac{4\pi^2r^2}{4\pi}=\frac{C^2}{4\pi},$$
$$(\delta)\quad A=\frac{\pi 4r^2}{4}=\frac{\pi d^2}{4}$$

Whence we see that the area of a circle is obtained by multiplying

(a) the square of its radius by $\pi=3\ 14159$,

(β) the radius by half the circumference,

(γ) the square of the circumference by $\frac{1}{4\pi}=\ 07957$,

(δ) the square of the diameter by $\frac{1}{4}\pi=\ 78539$

§ 38 Again, from the above formulæ we deduce

$$(\alpha)\quad r=\frac{1}{\sqrt{\pi}}A=\ 5641896\times A,$$
$$(\beta)\quad d=\frac{2}{\sqrt{\pi}}A=1\ 1283792\times A,$$
$$(\gamma)\quad c=2\sqrt{\pi}A=3\ 5449077\times A,$$

thus obtaining radius, diameter, and circumference from area

§ 39 *Area of a Circular Ring* —Let r and r_1 denote the radii of the outer and inner circles respectively (fig 17), then the area of the space between them

$$=\pi r^2-\pi r_1^2=\pi(r+r_1)(r-r_1)$$

The circles need not be concentric, and the reader should note that the area of the ring is equal to the area of an ellipse whose major and minor axes are $r+r_1$ and $r-r_1$ (see § 51)

§ 40 *Area of the Sector of an Annulus* —Let angle ACB$=\theta$ in fig 17, then the area of ABED

$$=\text{sector ACB}-\text{sector DCE}$$
$$=\tfrac{1}{2}r^2\theta-\tfrac{1}{2}r_1^2\theta,$$
$$=\tfrac{1}{2}\theta(r+r_1)(r-r_1)$$

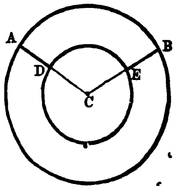


Fig 17.

Again, let AB $= l$, DE $= l_1$, and CA − CD $= r - r_1 = h$, then

$$r = \frac{l}{\theta} \text{ and } r_1 = \frac{l_1}{\theta}, \text{ therefore}$$

$$r + r_1 = \frac{1}{\theta}(l + l_1), \text{ and}$$

$$\text{area of sector} = \tfrac{1}{2}\theta(r + r_1)(r - r_1) = \tfrac{1}{2}\theta\left(\frac{l+l_1}{\theta}\right)h = \tfrac{1}{2}h(l + l_1)$$

§ 41 *Area of a Segment of a Circle* —(α) *When the radius and the angle subtended at the centre are given* —In fig 14, let AEB be a segment of a circle, then its area

$$\begin{aligned} &= \text{sector ACB} - \text{triangle ACB} \\ &= \tfrac{1}{2}r^2\theta - \tfrac{1}{2}r^2\sin\theta \ (\S\S\ 9,\ 34) \\ &= \tfrac{1}{2}r^2(\theta - \sin\theta) \end{aligned}$$

If the segment be greater than a semicircle $\sin\theta$ is negative and the formula becomes

$$\tfrac{1}{2}r^2(\theta + \sin\theta)$$

as is also geometrically evident

We might in a similar manner find the area of a segment of a circle

(β) when the chord and radius are given,
(γ) when the chord and its height are given,
(δ) when the radius and height of the chord are given,
(ε) when the chord and angle subtended by the chord are given

In all these cases the method of proceeding is obvious, a segment being the difference between a sector and a triangle

§ 42 *Area of a Lune* —Let ADB and ACB (fig 18) be two segments of circles, then the area of the lune ADBC

= segment ADB − segment ACB

Hence if we so choose our data that we can determine the areas of the two segments we have only to take their difference to find the area of the lune

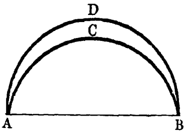


Fig 18

§ 43 *Area of a Circular Zone* —Let AB and CD (fig 19) be two parallel chords, then the area of the zone ABCD

$$\begin{aligned} &= \text{circle} - \text{segment AHB} - \text{segment DFC}, \\ \text{or} \quad &= \text{segment AED} + \text{trapezium ABCD} + \text{segment BGC} \\ &= 2\ \text{segment AED} + \text{trapezium ABCD} \end{aligned}$$

§ 44 The INFINITESIMAL CALCULUS (*q v*) furnishes a simple and elegant proof of the formula for the areas of a circle and a sector If $y = \phi(x)$ be the equation to a plane curve referred to rectangular axes, then the area between the curve, the axis of x and two ordinates corresponding to the abscissæ a and b is represented by the integral

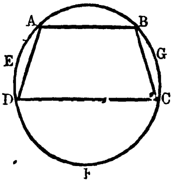


Fig 19

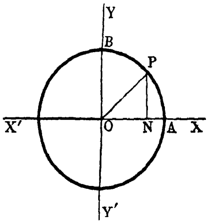


Fig 20

$$\int_a^b \phi(x)dx$$

Let x and y be the coordinates of P (fig 20), then if OP $= r$ the equation to the circle is $y^2 = r^2 - x^2$, and therefore

$$\text{area of quadrant AOB} = \int_0^r \sqrt{r^2 - x^2}\,dx$$

$$= \left[\frac{r^2}{2}\sin^{-1}\frac{x}{r} + \frac{x}{2}\sqrt{r^2 - x^2}\right]_0^r = \frac{r^2}{2} \times \frac{\pi}{2} = \frac{\pi r^2}{4}$$

and therefore area of whole circle $= \pi r^2$

§ 45 If the equation to a plane curve be given in polar coordinates, the area bounded by two radii and the curve is equal to

$$\tfrac{1}{2}\int_{\theta_1}^{\theta_2} r^2 d\theta,$$

where θ_1 and θ_2 are the values of θ corresponding to the limiting radii

For example, let AOP (fig 20) be θ, then area of circle

$$= \frac{2\pi r^2}{2}$$

The area of a sector can be found in a similar manner

B *The Parabola*

§ 46 *Length of an Arc of any Plane Curve* —If a plane curve be referred to rectangular axes, then the length of any arc of the curve

$$= s = \int\left\{1 + \left(\frac{dy}{dx}\right)^2\right\}^{\frac{1}{2}}dx = \int\left\{1 + \left(\frac{dx}{dy}\right)^2\right\}^{\frac{1}{2}}dy$$

taken between proper limits, *i e*, the extremities of the arc See INFINITESIMAL CALCULUS

§ 47 *Arc of a Parabola* —Let the axes of coordinates be the axis of x and the tangent at the vertex A (fig 21), then the equation to the parabola being $y^2 = 2mx$ where $m = 2a = \frac{1}{2}$ latus rectum we have

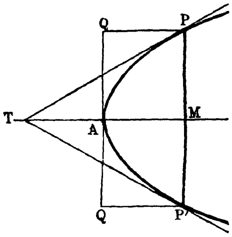


Fig 21

$$\frac{dx}{dy} = \frac{y}{m} \text{ and hence}$$

$$s = \text{arc AP} = \int_0^{y_1}\left\{1 + \frac{y^2}{m^2}\right\}^{\frac{1}{2}}dy$$

$$= \frac{y_1\sqrt{y_1^2 + m^2}}{2m} + \frac{m}{2}\log_e\left(\frac{y_1 + \sqrt{y_1^2 + m^2}}{m}\right),$$

therefore whole arc PAP $= \frac{y_1}{m}\sqrt{y_1^2 + m^2} + m\log_e\left(\frac{y_1 + \sqrt{y_1^2 + m^2}}{m}\right)$

Since $y_1^2 = 2mx_1$, the formula may be written

$$\text{arc PAP} = \sqrt{4x_1^2 + y_1^2} + \frac{y_1^2}{2x_1}\log_e\left(\frac{2x_1 + \sqrt{4x_1^2 + y_1^2}}{y_1}\right)$$

§ 48 *Area of a Parabola* —Taking the equation to the parabola in the form $y^2 = 4px$, we get

$$\text{area of segment PAP}' \text{ (fig 21)} = 2\int_0^{x_1} 2\sqrt{px}\,dx$$

$$= \tfrac{8}{3}p^{\frac{1}{2}}x_1^{\frac{3}{2}} = \tfrac{4}{3}x_1y_1 = \frac{y_1^3}{3p}$$

From these formulæ we see that the area of a parabolic segment varies directly as the cube of the square root of the abscissa, and directly as the cube of the ordinate, and that it is equal to $\frac{2}{3}$ rectangle PQQ′P′, or $\frac{4}{3}$ triangle PTP′

A similar relation holds for the segment cut off by any chord, and thus the area of any parabolic segment can be determined in terms of any data that are sufficient to determine the segment.

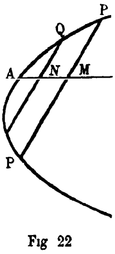


Fig 22

§ 49 *Area of a Parabolic Zone* —Let PM (fig 22) $= y_1$, QN $= y_2$, AM $= x_1$, AN $= x_2$, and let the ordinates be inclined to the axis at an angle α

$$\begin{aligned} \text{Area of zone PQQ}'\text{P}' &= \text{segment PAP}' - \text{segment QAQ}' \\ &= \frac{y_1^3 - y_2^3}{3p} \times \sin\alpha \end{aligned}$$

Now $y_1^2 = 4px_1$ and $y_2^2 = 4px_2$, therefore $\frac{y_1^2 - y_2^2}{4(x_1 - x_2)} = p$, and hence on substituting for p we have area of zone

$$= \tfrac{4}{3}(x_1 - x_2)\left(\frac{y_1^3 - y_2^3}{y_1^2 - y_2^2}\right)\sin\alpha = \tfrac{4}{3}\frac{x_1 - x_2}{y_1 + y_2}(y_1^2 + y_1y_2 + y_2^2)\sin\alpha$$

C *The Ellipse*

§ 50 *Circumference of an Ellipse* —The equation to the ellipse being $\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$, where a and b are the semiaxes, we have

$$\frac{dy}{dx} = -\frac{b^2x}{a^2y},\ \text{and therefore (fig 23)}$$

$$\text{arc of quadrant AB} = \int_0^a \left\{\frac{a^2 - e^2x^2}{a^2-x^2}\right\}^{\frac12} dx,\ \text{where}\ e^2 = \frac{a^2-b^2}{a^2}.$$

This integral may be shown to be equal to the series

$$-\frac{e^2}{2^2} - \frac{1}{2^2}\frac{3e^4}{4^2} - \frac{1}{2^2}\frac{3^2}{4^2}\frac{5e^6}{6^2} - \&c\Big),$$

a rapidly converging series when e is a small fraction

By taking more and more terms of the above series we can approximate as nearly as we please to the circumference of an ellipse For example, we have quadrant AB

$$\frac{\pi a}{2}\left(1-\frac{e^2}{4}\right) = \frac{\pi a}{2}\left(1-\frac{e^2}{2}\right)^{\frac12}$$

to a first approximation,

hence whole circumference

$$= \pi\left\{\frac{(2a)^2+(2b)^2}{2}\right\}^{\frac12}\ \text{nearly}$$

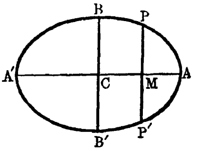


Fig 23

§ 51 *Area of an Ellipse* —We have at once

$$\text{area} = 4\int_0^a y\,dx = 4\frac{b}{a}\int_0^a \sqrt{a^2-x^2}\,dx$$

But $\int_0^a \sqrt{a^2-x^2}\,dx$ is the area of the quadrant of a circle of radius a Thus

$$\text{area of ellipse} = 4\frac{b}{a}\frac{\pi a^2}{4}\ (\S\ 44)$$
$$= \pi ab$$

The following proof is worth the reader's attention By a well-known theorem in conic sections the orthogonal projection of a circle on a given plane is an ellipse Now, if A denote the area of any plane figure, A′ the area of the projected figure, and θ the angle between the planes it can easily be shown, by dividing the two areas by planes indefinitely near to each other and perpendicular to the common section of the planes, that

$$A' = \cos\theta\ A$$

In the case of the circle and ellipse $A = \pi a^2$ and $\cos\theta = \frac{b}{a}$,

hence area of ellipse $= \pi a^2 \times \frac{b}{a} = \pi ab$

§ 52 *Area of an Ellipse in terms of a Pair of Conjugate Diameters* —Let a and b denote the semiconjugate diameters, and α the angle between them, then by an elementary property of the ellipse

$$ab = a'b'\sin\alpha$$

hence area of ellipse $= \pi a'b'\sin\alpha$

D *The Hyperbola*

§ 53 *Area of a Segment of an Hyperbola* —The equation of an hyperbola being $\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1$, we have

$$y = \frac{b}{a}\sqrt{x^2-a^2},\ \text{hence (fig 24)}$$

$$\text{area of the segment PAP}' = 2\frac{b}{a}\int_a^{x_1}\sqrt{x^2-a^2}\,dx$$

$$= \frac{b}{a}x_1\sqrt{x_1^2-a^2} - ab\log_e\left(\frac{x_1+\sqrt{x_1^2-a^2}}{a}\right)$$

$$= x_1y_1 - ab\log_e\left(\frac{x_1}{a}+\frac{y_1}{b}\right)$$

§ 54 *Area of a Sector of an Hyperbola* —The sector PAP′C is equal to triangle PCP′ − segment PAP′

$$= x_1y_1 - \left\{x_1y_1 - ab\log_e\left(\frac{x_1}{a}+\frac{y_1}{b}\right)\right\}$$

$$= ab\log_e\left(\frac{x_1}{a}+\frac{y_1}{b}\right)$$

§ 55 *Area of a Zone of an Hyperbola* —In fig 24 the zone PP′Q′Q

$$= \text{segment QAQ}' - \text{segment PAP}'$$

$$= x_2y_2 - ab\log_e\left(\frac{x_2}{a}+\frac{y_2}{b}\right) - x_1y_1 + ab\log_e\left(\frac{x_1}{a}+\frac{y_1}{b}\right)$$

$$= x_2y_2 - x_1y_1 - ab\log_e\left(\frac{ay_2+bx_2}{ay_1+bx_1}\right),\ \text{where}$$

of P and Q

If the axes of coordinates be inclined at an angle α, we multiply the above results by $\sin\alpha$ to obtain the correct areas

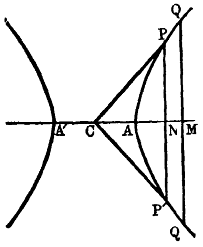


Fig 24

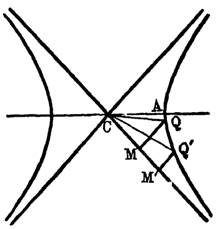


Fig 25

§ 56 *Area bounded by an Hyperbola and its Asymptotes* —The equation of an hyperbola referred to its asymptotes is of the form

$$xy = c^2$$

Let CM′ (fig 25) $= x_1$, CM $= x_2$, Q′M′ $= y_1$, QM $= y_2$, then, if α be the angle between the asymptotes,

$$\text{area of QMM}'\text{Q}' = \int_{x_2}^{x_1} y\sin\alpha\,dx$$

$$= c^2\sin\alpha\int_{x_2}^{x_1}\frac{dx}{x} = c^2\sin\alpha\log_e\left(\frac{x_1}{x_2}\right) = c^2\sin\alpha\log_e\left(\frac{y_2}{y_1}\right),$$

$$x_1 = \frac{c^2}{y_1}\ \text{and}\ x_2 = \frac{c^2}{y_2}$$

Now $\quad c^2 = \frac{a^2+b^2}{4}$ and $\sin\alpha = \frac{2ab}{a^2+b^2}$, and therefore

$$(\alpha)\qquad \text{area} = \tfrac12 ab\log_e\left(\frac{x_1}{x_2}\right) = \tfrac12 ab\log_e\left(\frac{y_2}{y_1}\right)$$

Again, let MM′ $= x_1 - x_2 = p$, then

$$c^2 = x_1y_1 = x_2y_2 = \frac{py_1y_2}{y_2-y_1},\ \text{therefore}$$

$$(\beta)\qquad \text{QMM}'\text{Q}' = \frac{py_1y_2}{y_2-y_1}\log_e\left(\frac{x_1}{x_2}\right)\sin\alpha = \frac{py_1y_2}{y_2-y_1}\log_e\left(\frac{y_2}{y_1}\right)\sin\alpha$$

Again, since

$$\tfrac12 x_1y_1\sin\alpha = \tfrac12 c^2\sin\alpha = \tfrac12 x_2y_2\sin\alpha$$

we have $\quad$ triangle QCM = Q′CM′, and hence

the sector QCQ′ = QMM′Q′

The corresponding results for a rectangular hyperbola are obtained by substituting in the above formulæ $\frac12 a$ for c^2 and 1 for $\sin\alpha$.

SECTION III —PLANE IRREGULAR, RECTILINEAL AND CURVILINEAL FIGURES

A *Irregular Rectilineal Figures*

§ 57 The area of any irregular polygon can be found by dividing it into triangles, trapeziums, &c, in the most convenient manner, and adding together all the areas For example,

ABCDEF (fig 26) = CKB + BKHA + AHF + FGE + EGID + DIC

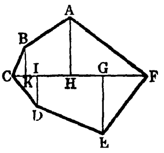


Fig 26

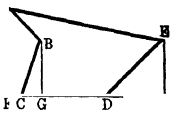


Fig 27

It may sometimes happen that some of the component figures have to be subtracted instead of added, for example,

ABCDE (fig 27) = AFHE + BCG − AFGB − EDH

§ 58 Again, the irregular rectilineal figure $P_1P_2 \ldots P_8P_9$ (fig 28) can be broken up into a series of triangles and trapeziums as shown in the figure, and hence its area can be found

§ 59 A figure made up of straight lines may be measured by cutting it up into triangles by lines drawn from some one vertex to the others For example (fig 29), If the polygon be concave some of the triangles will have to be subtracted.

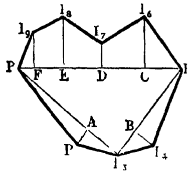


Fig 28

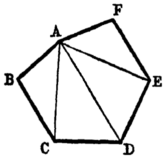


Fig 29

§ 60 *Area of a Polygon in terms of the Coordinates of its Angular Points* —Let the coordinates of P, Q, R (fig 30) be (x_1, y_1), (x_2, y_2), and (x_3, y_3) respectively, and let the axes be inclined at an angle α Draw PL QM and RN parallel to OY then

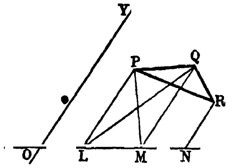


Fig 30

$$LM = OM - OL = x_2 - x_1,$$

$$MN = ON - OM = x_3 - x_2,$$

and

$$NL = ON - OL = x_3 - x_1$$

Now $\qquad PQR = PLMQ + QMNR - PLNR$

But $\qquad PLMQ = PLM + QMP = PLM + QLM$

$$= \tfrac{1}{2}PL \cdot LM \sin\alpha + \tfrac{1}{2}QM \cdot LM \sin(180^\circ - \alpha) \ (\S\ 9,\ \beta)$$

$$= \tfrac{1}{2}(x_2 - x_1)(y_1 + y_2) \sin\alpha$$

Similarly $\qquad QMNR = \tfrac{1}{2}(x_3 - x_2)(y_2 + y_3) \sin\alpha,$

and $\qquad PLNR = \tfrac{1}{2}(x_3 - x_1)(y_3 + y_1) \sin\alpha$, hence

$$\text{area of } PQR = \tfrac{1}{2}\sin\alpha\{y_1(x_2 - x_3) + y_2(x_3 - x_1) + y_3(x_1 - x_2)\},$$

or in the notation of determinants

$$= \tfrac{1}{2}\sin\alpha \begin{vmatrix} 1 & 1 & 1 \\ x_1 & x_2 & x_3 \\ y_1 & y_2 & y_3 \end{vmatrix}$$

When the axes are rectangular $\sin\alpha = \sin 90^\circ = 1$, and the formula for the area becomes

$$\tfrac{1}{2}\{y_1(x_2 - x_3) + y_2(x_3 - x_1) + y_3(x_1 - x_2)\}$$

$$= \tfrac{1}{2}\begin{vmatrix} 1 & 1 & 1 \\ x_1 & x_2 & x_3 \\ y_1 & y_2 & y_3 \end{vmatrix}$$

§ 61 The area of any rectilineal figure of n sides can be found by taking any point within the figure and joining it to the n vertices of the figure thus dividing it into n triangles the area of each of which can be obtained as in the preceding case

We may however find the area of the figure directly

For example, in fig 31

$$PQRST = PP'T'T + TT'S'S + SS'R'R - RR'Q'Q - QQ'P'P,$$

and in fig 32

$$PQRSTU = PP'U'U + RR'Q'Q + TT'S'S - PP'Q'Q - RR'S'S - TT'U'U$$

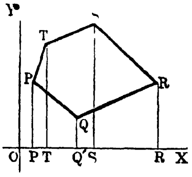


Fig 31

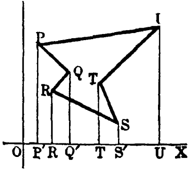


Fig 32

B *Irregular Curvilineal Figures*

§ 62 *Length of any Curve* —If we divide the given arc into an even number of intervals and regard these as approximately circular, we can find an approximation to the length of the arc by means of Huygens's formula § 32 For example, if we divide ABC (fig 33) into four parts in D, B, and E, and draw the chords AD, AB, DB, BE, BC, and EC, then

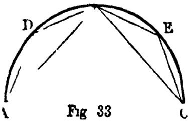


Fig 33

$$\text{arc } AC = AD + DB + BE + EC + \tfrac{1}{3}(AD + DB + BE + EC - AB - BC)$$

approximately

For other methods of approximation, see Rankine's *Rules and Tables*

§ 63 *Area of an Irregular Curvilineal Figure* —For rough approximations the following, called the trapezoidal method, may be used —

Divide A_1A_n (fig 34) into n equal parts, and through the points of division draw the ordinates, called by surveyors offsets, A_1P_1, A_2P_2, &c

Fig 34

Let $\qquad A_1P_1 = s_1,\ A_2P_2 = s_2,\ \&c,\ A_nP_n = s_n$, and

$$A_1A_2 = A_2A_3 = \dots = A_{n-1}A_n = a$$

Join P_1P_2, P_2P_3, &c, then the area of the polygon $A_1A_nP_nP_2P_1$

$$= A_1A_2P_2P_1 + A_2A_3P_3P_2 + \dots + A_{n-1}A_nP_nP_{n-1}$$

$$= \tfrac{1}{2}a(s_1 + s_2) + \tfrac{1}{2}a(s_2 + s_3) + \dots + \tfrac{1}{2}a(s_{n-1} + s_n) \quad (\S\ 13,\ \alpha)$$

$$= a\{\tfrac{1}{2}(s_1 + s_n) + s_2 + s_3 + \dots + s_{n-1}\}$$

If we take n sufficiently great the difference between the area of the polygon and the curvilineal figure can be made as small as we please, in other words, the smaller we make a the more accurately will the above formula represent the area of the curvilineal figure

The curve may either be wholly convex or wholly concave to the line A_1A_n or partly convex and partly concave

§ 64 *Simpson's Rule* —Let A_1A_n (fig 34) be divided into an *even* number of equal parts and as before through the points of division draw the ordinates A_1P_1 A_2P_2 &c

Let $A_1A_3P_3P_1$ (figs 35 36) be a part of the figure thus divided join P_1P_3 and through P_2 draw BC parallel to P_1P_3 to meet A_1P_1 in B and A_3P_3 in C Conceive a parabola to be drawn through $P_1P_2P_3$ having its axis parallel to the ordinates then

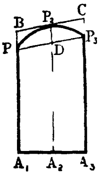


Fig 35

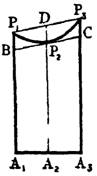


Fig 36

$$A_1P_1P_2P_3A_3 = \text{trapezium } A_1P_1DP_3A_3 \pm \text{parabolic segment } P_1P_2P_3$$

$$= a(s_1 + s_3) \pm \tfrac{4}{3}a\{s_2 \sim \tfrac{1}{2}(s_1 + s_3)\} = \tfrac{1}{3}a(s_1 + 4s_2 + s_3)$$

Now when the points P_1 P_2 P_3 are near each other the parabolic curve will coincide very nearly with the given curve hence

$$A_1P_1P_2P_3A_3 = \tfrac{1}{3}a(s_1 + 4s_2 + s_3) \text{ very nearly}$$

Similarly $\qquad A_3P_3P_5A_5 = \tfrac{1}{3}a(s_3 + 4s_4 + s_5)$ &c

hence whole area of figure

$$= \tfrac{1}{3}a\{s_1 + s_n + 2(s_3 + s_5 + \dots + s_{n-2}) + 4(s_2 + s_4 + \dots + s_{n-1})\}$$

whence the rule —add together the two extreme ordinates twice the sum of the intermediate odd ordinates and four times the sum of the even ones, and multiply this result by one third of the common distance between the ordinates the result is the area —*accurately* if the curved boundary be the arc of a parabola in other cases approximately

The curve may either be wholly convex or wholly concave to the line A_1A_n, or partly convex and partly concave provided in the latter case the points of contrary flexure occur only at the odd ordinates, for otherwise the intermediate arcs could not be even approximately parabolic When points of contrary flexure occur ordinates may be drawn at these points and the intermediate arcs being found separately may be added to obtain the whole area

§ 65 In the two preceding sections we investigated two formulæ for approximating to the areas of curvilinear figures We now proceed to consider the subject more generally

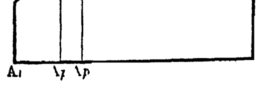


Fig 37

Let the equation to the curve $P_1P_pP_{n+1}$ (fig 37) agree with the equation $y = A + Bx + Cx^2 + \qquad + Kx^n$ for $n+1$ points between P_1 and P_{n+1}, then the area of the curvilinear figure bounded by the straight lines A_1P_1, A_1A_{n+1}, and $A_{n+1}P_{n+1}$ and the curve P_1P_{n+1} will agree very nearly with the curvilinear figure bounded by the same straight lines and the curve whose equation is $y = A + Bx + Cx^2 + \qquad + Kx^n$, and the greater the number of common points the closer will be the agreement

Let A_1A_{n+1} be divided into n equal parts, each equal to h, then $A_1A_{n+1} = nh$ Now

when $x = 0$, $y = y_1 = A$,

when $x = h$, $y = y_2 = A + Bh + Ch^2 + \qquad + Kh^n$,

when $x = 2h$, $y = y_3 = A + B(2h) + C(2h)^2 + \qquad + K(2h)^n$,

when $x = ph$, $y = y_{p+1} = A + B(ph) + C(ph)^2 + \qquad + K(ph)^n$,

when $x = nh$, $y = y_{n+1} = A + B(nh) + C(nh)^2 + \qquad + K(nh)^n$

From these $n+1$ equations the $n+1$ quantities A, B, $\qquad$ K can be determined as functions of y_1, y_2, $\qquad$ y_{n+1}, and h

Next let A_1A_{n+1} be divided into m equal parts each equal to h Thus $mh = nh$ and hence $h = \frac{nh}{m}$

Now the area of the rectangle $A_pA_{p+1}P_pR = A_pA_{p+1} \times A_pP_p$

But
$$A_pP_p = y_p = A + B(ph) + C(ph)^2 + \qquad + K(ph)^n$$
$$= A + B\frac{p\,nh}{m} + C\left(\frac{p\,nh}{m}\right)^2 + \qquad + K\left(\frac{p\,nh}{m}\right)^n,$$

and
$$A_pA_{p+1} = h = \frac{nh}{m},$$

therefore area of A_pR
$$nh\left\{\frac{A}{m} + Bnh\frac{p}{m^2} + Cn^2h^2\frac{p^2}{m^3} + \qquad + Kn^nh^n\frac{p^n}{m^{n+1}}\right\}.$$

Hence the area of the whole figure
$$= \mathrm{L}_{m=\infty}\sum_{p=1}^{p=m} nh\left\{\frac{A}{m} + Bnh\frac{p}{m^2} + Cn^2h^2\frac{p^2}{m^3} + \qquad + Kn^nh^n\frac{p^n}{m^{n+1}}\right\}$$
$$= \mathrm{L}_{m=\infty} nh\left\{A\frac{S_0}{m} + Bnh\frac{S_1}{m^2} + Cn^2h^2\frac{S_2}{m^3} + \quad . \quad + Kn^nh^n\frac{S_n}{m^{n+1}}\right\}$$

where
$$S_n = 1^n + 2^n + 3^n + \qquad + m^n.$$

Now if we take the limit of each of the terms
$$\frac{S_0}{m},\ \frac{S_1}{m^2},\ \frac{S_2}{m^3},\ \qquad \frac{S_n}{m^{n+1}},$$

we obtain area of curvilinear figure
$$= nh\left\{A + \frac{B}{2}nh + \frac{C}{3}n^2h^2 + \qquad + \frac{K}{n+1}n^nh^n\right\}$$

From this general result we can deduce "Simpson's Rule" and also another rule called "Weddle's Rule"

Thus let $n = 2$, that is, assume that the curve under consideration has three points in common with the curve whose equation is $y = A + Bx + Cx^2$, i e, with a parabola, then
$$y_1 = A,$$
$$y_2 = A + Bh + Ch^2,$$
$$y_3 = A + 2Bh + 4Ch^2$$

Now the area is approximately
$$= 2h\{A + \tfrac{1}{2}B2h + \tfrac{1}{3}C2^2h^2\}$$
$$= \tfrac{1}{3}h\{6A + 6Bh + 8Ch^2\}$$
$$= \tfrac{1}{3}h\{y_1 + 4y_2 + y_3\},$$ Simpson's Rule

If we now put $n = 6$, we have area of curvilinear figure
$$= 6h\{A + \tfrac{1}{2}B6h + \tfrac{1}{3}C6^2h^2 + \tfrac{1}{4}D6^3h^3 + \tfrac{1}{5}E6^4h^4 + \tfrac{1}{6}F6^5h^5 + \tfrac{1}{7}G6^6h^6\}$$

Now
$$y_1 = A,$$
$$y_2 = A + Bh + Ch^2 + \qquad + Gh^6,$$
$$y_7 = A + B(6h) + C(6h)^2 + \quad . \quad G(6h)^6$$

From this system of equations we can determine A, B, C, $\qquad$ G, *and substituting the values so obtained in the above expression we obtain the following* remarkable formula for the approximate area

This formula, called Weddle's Rule, gives the closest approximation to the curvilinear area that can be obtained by any simple rule

We are now in a position to find the approximate area of any irregular plane figure For the given figure can be divided into plane rectilinear and curvilinear figures, the areas of which can be separately determined by the rules already given For example, APQRS (fig 38)

$$= ABC + APD + BRC - DQB - ASC$$

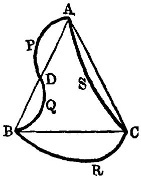


Fig 38

PART II SOLIDS

SECTION I SOLIDS CONTAINED BY PLANES.

A *Prisms, Pyramids, and Prismatoids*

§ 66 *Volume of a Right Prism* —First let the prism be a rectangular parallelepiped (fig 39), and let the side AB contain a units of length, BC b units of length, and CD c units of length If we divide AB into a equal parts, BC into b equal parts, and CD into c equal parts, and if, through the points of division we draw planes parallel to the sides of the parallelepiped, these planes will divide it into a series of parallelepipeds, whose edges are each equal to the unit of length Each horizontal layer contains ab of these cubes, and since there are c layers the whole number of cubes will be abc But each of these is the unit of volume, and therefore

Fig. 39.

volume of ABCD $= abc = ab \times c =$ area of base ABC × altitude c

In the above demonstration we have assumed the edges to be commensurable, but from § 2 it follows that the proof will hold also when the edges are incommensurable If the parallelepiped be cut by a plane BGE it will be divided into two equal triangular right prisms, and hence

volume of right triangular prism $= \frac{1}{2}ab \times c =$ area of its base × altitude

Since every prism can be divided into triangular prisms as in fig *40, we have at once*

volume of right prism A′ABCDE = A′ABC + A ACD + A′ADE
= ABC × BB′ + ACD × CC′ + ADE × DD′
= (ABC + ACD + ADE) × altitude
(since BB′ = CC′ = DD′ = altitude)
= area of base ABCDE × altitude.

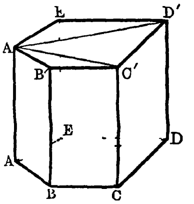


Fig 40

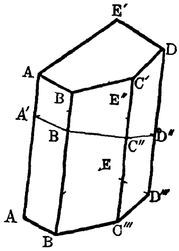


Fig 41

§ 67 *Volume of an Oblique Prism* —Draw the right section A B″C D E″ (fig 41), and let A′ denote its area and A the area of the base A′B′C′D′E′ *Let l denote the length of the prism, h its* altitude, and α the angle between the planes A′B C D′E′ and A′B′C′D″E″

Conceive the part above the right section placed at the other extremity of the prism Then we have a right prism, whose volume $= A' \times l$ (§ 66), but $A' = A\cos\alpha$, since A′ is the projection of A (§ 51),

and
$$l = \frac{h}{\cos\alpha},$$ hence

$$\text{volume} = A' \times l = A\cos\alpha \times \frac{h}{\cos\alpha} = A \times h,$$

or the volume of any prism is equal to the area of its base multi-

§ 68 *Surface of a Prism* —Since the lines A′B , B C , &c (fig 41), which make up the perimeter of the right section are all in one plane perpendicular to the parallel edges A A , B B , &c , they are perpendicular to these edges and are therefore the altitudes of the parallelograms A B B A′ , B C C B , &c , respectively The lateral surface of the prism is equal to the sum of these parallelograms, and therefore

$$= A'A \times A\,B + BB \times B\,C + $$
$$= A'A'(A\,B + B\,C + \qquad),$$

since $A'A' = BB = \&c$,

or the lateral surface of any prism is equal to the perimeter of its right section multiplied by the length of the prism

If the prism be *right*, that is, if the faces be perpendicular to the base, then its lateral surface is equal to the perimeter of its base multiplied by its length

The whole surface of any prism is obtained by adding to the lateral surface the areas of its bases

§ 69 If the prism be *regular* that is, if the bases be regular polygons, then

area of base $= a^2 \times \frac{n}{4}\cot\frac{180^\circ}{n}$ (§ 18, γ), where n is the number of sides each of length a, and therefore

$$\text{volume} = a^2 \times \frac{n}{4}\cot\frac{180^\circ}{n} \times h,$$

where h is the altitude of the prism

Again, if the prism be right and regular, then

$$\text{its lateral surface} = nah + 2a^2 \times \frac{n}{4}\cot\frac{180^\circ}{n}$$

§ 70 *Volume of a Pyramid* —Let VABC (fig 42) be for simplicity a triangular pyramid Divide VA into n equal portions, and through the points of section draw planes parallel to the base ABC and through BC and through the intersections of these planes with VBC draw planes parallel to VA Let h denote the altitude of the pyramid, then the distance of the base of the r^{th} prism from the vertex V

$$= r \times \frac{h}{n},$$

and, if A denote the area of ABC, we have

$$\frac{\text{base of } r^{\text{th}} \text{ prism}}{A} = \frac{r^2h^2}{n} \times \frac{1}{h^2} = \frac{r^2}{n^2},$$

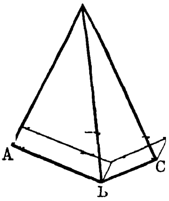


Fig 42

since, by a well known theorem in solid geometry, the areas of sections of a pyramid made by planes parallel to the base are proportional to the squares of their altitudes

Thus we have

base of r^{th} prism $= \frac{r^2}{n^2}A$, and therefore

$$\text{its volume} = \frac{r}{n}A \times \frac{n}{n} \text{ (§ 67)}$$
$$= \frac{hA}{n^3} \times r^2$$

Therefore volume of whole pyramid

$$= hA\,\mathrm{L}_{n=\infty}\frac{1^2+2^2+\qquad+r^2+\qquad}{n^3}$$
$$= hA\,\mathrm{L}_{n=}\ \frac{n(n+1)(2n+1)}{}$$

or the volume of any pyramid is equal to one third of the area of its base multiplied by its height

From this we see that pyramids on equal bases are to one another as their altitudes

If the pyramid be *regular*, that is, if its base be a regular polygon the perpendicular through whose centre passes through the vertex,

180°,

§ 71 *Surface of a Regular Pyramid* —The lateral surface of the regular pyramid VABCDEF (fig 43) is equal to the sum of the areas of the n congruent triangles which make up the lateral surface of the pyramid

Now area of triangle VAB $= \frac12$AB × VG, hence whole lateral surface $= \frac12 n$AB VG $= \frac12 nal$, where l is the slant height and a the length of the side of the base

Again, if VO $= h =$ altitude of pyramid, we have

$$l = VG = \sqrt{VO^2 + OG^2} = \sqrt{h^2 + \frac{a}{4}\cot^2\frac{180^\circ}{n}},$$

therefore whole surface = base + lateral surface

$$= a^2 \times \frac{n}{4}\cot\frac{180^\circ}{n} + \tfrac12 na\sqrt{h + \frac{a}{4}\cot^2\frac{180^\circ}{n}}$$
$$= \frac{na}{2}\left(\frac{a}{2}\cot\frac{180^\circ}{n} + \sqrt{h^2 + \frac{a^2}{4}\cot^2\frac{180^\circ}{n}}\right).$$

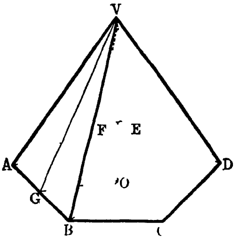


Fig 43

§ 72 *The Prismatoid* —If we have a polyhedron whose bases are two polygons in parallel planes the number of sides in each being the same or different, and if we so join the vertices of these bases that each line in order forms a triangle with the preceding line and one side of either base the figure so formed is called a "prismatoid, and holds in stereometry a position similar to that of the trapezium in planimetry To make the investigation of the volume of the prismatoid as simple as possible, we take the case where the lower base is a polygon of four and the upper one of three sides

Let ABCDEFG (fig 44) be the prismatoid, of which ABC or A_1 is the upper and DEFG or A_3 the lower base, and let HLM be the section equidistant from the bases Take any point P in this section and join it to the corners of the prismatoid We thus divide the polyhedron into two pyramids PABC and PDEFG, and a series of polyhedra of which CPDE may be taken as a specimen

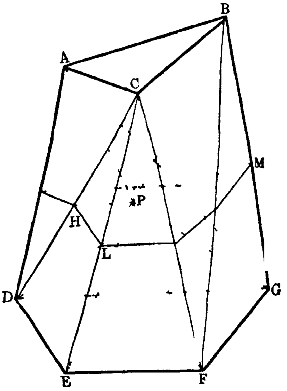


Fig 44

Let h be the altitude of the prismatoid then $\frac12 h$ is the altitude of each of the pyramids PABC, PDEFG, and hence

$$\text{volume of PABC} = \tfrac16 hA_1, \text{ and}$$
$$\text{volume of PDEFG} = \tfrac16 hA_3$$

Again join PH, PL, and LD, then

volume of CPDE = 2 volume of CPDL
since DE = 2HL,
and volume of CPDL = 2 volume of CPHL,
hence volume of CPDE = 4 volume of CPHL

Now volume of CPHL $= \frac16 h$ × area of HLP, and therefore volume of CPDE $= \frac46 h$ × area of HLP

Similarly the volume of every such polyhedron is $\frac46 h$ × the area of its own portion of the middle section Hence if A denote the area of the middle section we have

$$\text{volume of prismatoid} = \tfrac16 hA_1 + \tfrac16 hA_3 + \tfrac46 hA_2$$
$$= \tfrac16 h(A_1 + 4A_2 + A_3)$$

§ 73 *Volume of the Frustum of a Pyramid* —Let AA BB CC′ (fig 45) be a frustum of the pyramid VABC′ and let A_1 and A_3 denote the areas of the ends ABC ABC respectively Let VP $= x =$ altitude of pyramid VABC , and let PQ $= h =$ altitude of frustum

Now $\left(\frac{x}{x+h}\right)^2 = \frac{A_3}{A_1}$, whence $x = \frac{h\sqrt{A_3}}{\sqrt{A_1} - \sqrt{A_3}}$

Again frustum = VA'BC − VA B C

$$=\tfrac{1}{3}\left\{A_1(x+h)-A_3x\right\}$$

$$=\tfrac{1}{3}\left\{A_1\left(\frac{h\sqrt{A_1}}{\sqrt{A_1}-\sqrt{A_3}}\right)-A_3\left(\frac{h\sqrt{A_3}}{\sqrt{A_1}-\sqrt{A_3}}\right)\right\}$$

$$=\tfrac{1}{3}h(A_1+\sqrt{A_1A_3}+A_3)\,,$$

a formula which applies to the frusta of all pyramids regular and irregular

The above result may be otherwise expressed For, let A B $=a_1$ and A B $=a_3$, then, if A B C be a section equidistant from the ends of the frustum, A B $=a_2=\frac{1}{2}(a_1+a_3)$

Now $A_1=pa_1^2$ and $A_3=pa_3^2$ (see § 70), hence A_2 = area of A B C $=pa_2^2=p\left(\frac{a_1+a_3}{2}\right)^2$, which gives

$$4A_2=pa_1^2+2pa_1a_3+pa_3^2=A_1+2\sqrt{A_1A_3}+A_3$$

therefore volume of frustum

$$=\tfrac{1}{6}h(2A_1+2\sqrt{A_1A_3}+2A_3)=\tfrac{1}{6}h(A_1+4A_2+A_3)$$

or the volume of the frustum of a pyramid is obtained by adding the areas of the ends to four times the area of the middle section and multiplying the sum by one sixth of the altitude

The above result can be obtained at once from § 72, since *ABCA B C* is a prismatoid with similar bases

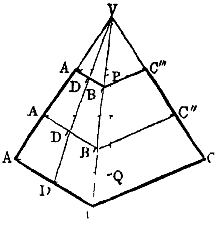


Fig 45

§ 74 *Surface of the Frustum of a Regular Pyramid* —In fig 45 let the perimeter of $A_1=p_1$, that of $A_2=p_2$ and that of $A_3=p_3$ and let VD $=l_1$, VD $=l_3$ and therefore D D = VD − VD $=l_1-l_3=l$ The lateral surface of the frustum is equal to the difference between the lateral surfaces of the pyramids VABC and VA B C

$$=\tfrac{1}{2}p_1l_1-\tfrac{1}{2}p_3l_3$$

But, since $\frac{l_1}{l_3}=\frac{a_1}{a_3}=\frac{na_1}{na_3}=\frac{p_1}{p_3}$ we have $l_1=\frac{p_1l}{p_1-p_3}$ and $l_3=\frac{p_3l}{p_1-p_3}$, therefore lateral surface of frustum

$$=\tfrac{1}{2}l\left(\frac{p_1^2-p_3^2}{p_1-p_3}\right)=l\left(\frac{p_1+p_3}{2}\right)=lp_2\,,$$

or the lateral surface of the frustum of a regular pyramid is equal to the product of the slant height and the perimeter of the section equidistant from the ends

Otherwise —The top and base being regular polygons the inclined faces are congruent trapeziums Let l be the height of each trapezium, and let there be n of them, then

$$\text{area of each face}=\frac{l}{2}\left(\frac{p_1}{n}+\frac{p_3}{n}\right),$$

and therefore the area of lateral surface $=\frac{l}{2}(p_1+p_3)$

§ 75 *If h the altitude of the frustum be given* we deduce the slant height and then proceed as before Thus let VP $=h_3$ VQ $=h_1$ and using the same notation as in §§ 72, 73 and 74 we have

$$\frac{h_1}{h_1-h_3}= \quad\text{which gives } h_1=\frac{a_1(h_1-h_3)}{a_1-a_3}=\frac{a_1h}{a_1-a_3}$$

Again $\quad l_1=h_1+\frac{1}{4}a_1\cot\frac{180^\circ}{n}$, and $l=\left(\frac{a_1-a_3}{a_1}\right)l_1$

whence l is known since l_1 is known in terms of h

When the pyramid is irregular the lateral planes are non congruent trapeziums the areas of which can be found separately by § 12 and hence the whole surface

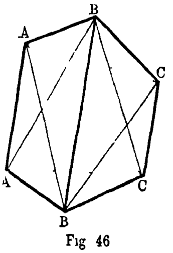


Fig 46

§ 76 *Volume of the Frustum of a Triangular Prism* —Let A denote the area of ABC (fig 46), and let h_1, h_2, h_3 be the altitudes of A B C respectively with reference to the plane ABC Divide the frustum into three pyramids B A AC B ABC and B ACC by the planes B AC and B A C These three pyramids are respectively equal to B A AC B ABC and ABCC hence volume of frustum $=\frac{1}{3}h_1A+\frac{1}{3}h_2A+\frac{1}{3}h_3A$

$$=\tfrac{1}{3}A(h_1+h_2+h_3)$$

§ 77 If the prism be right or oblique, the volume of a frustum is equal to one third of the area of its right section multiplied by the sum of the parallel edges For divide the frustum AA'B C' (fig 47) into two frusta by a plane A' B C'' of area A at right angles to the edges, then

$$\text{AA B C}=\text{AA}'\text{B C}'+\text{A}''\text{A}'\text{B C}'$$

$$=\tfrac{1}{3}\text{A}(\text{AA}+\text{BB}'+\text{CC})+\tfrac{1}{3}\text{A}(\text{A A}+\text{B B}+\text{C C}'')$$

$$=\tfrac{1}{3}\text{A}(\text{AA}'+\text{BB}+\text{CC}'+\text{A}'\text{A}+\text{B B}+\text{C C})$$

$$=\tfrac{1}{3}\text{A}(\text{AA}+\text{BB}+\text{CC})$$

Again, since every prism can be divided into triangular prisms, we can find by repeated applications of the above proposition the volume of the frustum of any prism whatever For example if

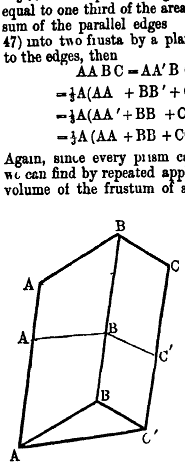


Fig 47

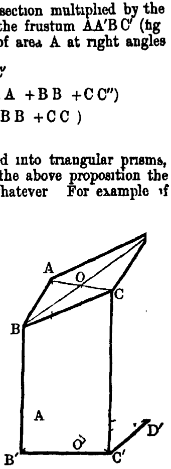


Fig 48

the base of the frustum of a right prism AA B C D (fig 48) be a rectangle 12 feet by 6 feet, and the parallel edges in order 6, 4, 10, and 12 feet, then

$$\text{A}=\text{area of base}=12\times6=72\text{ square feet}$$

$$\text{Frustum}=\text{ABCA B C}+\text{ADCA D C}'$$

$$=\tfrac{1}{3}\times\tfrac{1}{2}\text{A}(\text{AA}+\text{BB}+\text{CC})+\tfrac{1}{3}\times\tfrac{1}{2}\text{A}(\text{AA}+\text{CC}+\text{DD})$$

$$=\tfrac{1}{6}\text{A}(2\text{AA}'+2\text{CC}+\text{BB}+\text{DD})=576$$

§ 78 *Volume of a Wedge* —The wedge (fig 49) being merely the frustum of a triangular prism, we have at once

$$\text{volume}=\tfrac{1}{3}\text{A}(\text{FE}+\text{AD}+\text{BC}),$$

where A is the area of its right section, otherwise, *the wedge may be considered a prismatoid whose upper base is a straight line*, and hence its volume $=\frac{1}{6}h(4A_2+A_3)$, since $A_1=0$

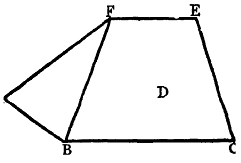


Fig 49

B *Regular Polyhedra*

§ 79 The regular polyhedra are five in number, namely, the *tetrahedron*, *cube*, *octahedron*, *dodecahedron*, and *icosahedron*, whose solid angles are formed respectively by three equilateral triangles, three squares, four equilateral triangles, three pentagons, and five equilateral triangles

Since a regular polyhedron admits of having a sphere inscribed within it and described about it, it can easily be shown that the volume of the polyhedron

$$=a^3\times\frac{nl}{24}\times\frac{\qquad}{\left\{\left(\frac{\pi}{m}+\frac{\pi}{n}\right)\cos\left(\frac{\pi}{m}-\frac{\pi}{n}\right)\right\}^{\frac{1}{2}}},$$

and from § 18 γ, it follows that the surface of the polyhedron

$$=a^2\times\frac{ln}{4}\cot\frac{\pi}{n}\,,$$

where l = the number of faces,
m = the number of faces in each solid angle,
n = the number of edges in each face,
and a = the length of each side

The following table contains the surfaces and volumes for the five regular polyhedra whose edge is 1

Polyhedron	Surface	Volume
Tetrahedron	1.7320508	0.1178511
Cube	6.0000000	1.0000000
Octahedron	3.4641016	0.4714045
Dodecahedron	20.6457788	7.6631189
Icosahedron	8.6602540	2.1816950

The surface and volume of a regular polyhedron whose edge is a is obtained by multiplying the surface and volume of a similar polyhedron whose edge is 1 by a^2 and a^3 respectively

SECTION II SOLIDS CONTAINED BY SURFACES WHICH ARE NOT ALL PLANES

A *The Cylinder*

§ 80 *Volume of a Cylinder* (fig 50) —Inscribe in the cylinder a polygonal prism of which the number of sides may be increased indefinitely Then in the limit the base of the prism becomes the base of the cylinder, and the volume of the prism the volume of the cylinder Now by § 67 we have

volume of prism = area of base × altitude,
hence volume of cylinder = area of base × altitude

§ 81 *Surface of a Right Cylinder* —As above, in the limit the base of the prism becomes the base of the cylinder, and the surface of the prism the surface of the cylinder Now the lateral surface of prism

= perimeter of right section × length
= perimeter of base × length, in the case of a right prism (§ 68),

hence lateral surface of right cylinder = circumference of base × length

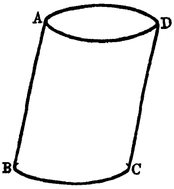


Fig 50

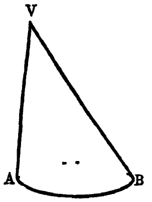


Fig 51

B *The Cone*

§ 82 *Volume of a Cone* (fig 51) —Inscribe within the cone a pyramid of which the number of sides may be indefinitely increased, then in the limit the base of the pyramid becomes the base of the cone and the volume of the pyramid the volume of the cone

By § 70 volume of pyramid = ⅓ base × altitude,
and hence volume of cone = ⅓ base × altitude

§ 83 *Volume of the Frustum of a Cone* —From § 73 we find that the volume of the frustum of a pyramid

$$=\tfrac{1}{3}h(A_1+\sqrt{A_1A_3}+A_3),$$

hence, since in the limit the frustum of the pyramid becomes the frustum of the cone, we have

$$\text{volume of conical frustum}=\tfrac{1}{3}h(A_1+\sqrt{A_1A_3}+A_3),$$

where A_1 and A_3 are the areas of the terminating planes of the frustum

Let the terminating planes be circles of radii r_1 and r_3, then volume of frustum

$$=\tfrac{1}{3}h(\pi r_1^2+\pi r_1r_3+\pi r_3^2)=\tfrac{1}{3}\pi h(r_1^2+r_1r_3+r_3^2)$$

Again, by the same section we have

$$\text{volume of frustum of pyramid}=\tfrac{1}{6}h(A_1+4A_2+A_3),$$

therefore
$$\text{volume of conical frustum}=\tfrac{1}{6}\pi h(r_1^2+4r_2^2+r_3^2),$$

where r_2 is the radius of the circular section parallel to the terminating planes and equidistant from them

§ 84 *Surface of a Right Cone* —The lateral surface of a regular pyramid is by § 71

$$=\tfrac{1}{2}\text{perimeter of base}\times\text{slant height},$$

hence, since in the limit the surface of the pyramid becomes the surface of the cone, the lateral surface of a right cone is equal to half the circumference of its base multiplied by the slant height

Thus the lateral surface of a right cone of slant height l and the radius of whose base is r is equal to

$$\tfrac{1}{2}\times 2\pi r\times l=\pi rl,$$

and
$$\begin{aligned}\text{whole surface}&=\text{lateral surface}+\text{area of base}\\&=\pi rl+\pi r^2\\&=\pi r(l+r)\end{aligned}$$

Again, if h, the altitude of the cone, be given, we have

$$l=\sqrt{h^2+r^2},$$

and therefore whole surface $=\pi r(\sqrt{h^2+r^2}+r)$

§ 85 *Surface of the Frustum of a Right Cone* —The lateral surface of the frustum of a regular pyramid is equal to the product of the slant height and the perimeter of its middle section (§ 74), hence in the limit we find that the lateral surface of the frustum of a right cone is equal to the product of its slant height and the circumference of the section equidistant from its parallel faces

Let r_1 and r_3 denote the radii of the ends of the frustum, and l the length of the slant height then

$$r_2=\tfrac{1}{2}(r_1+r_3)=\text{radius of middle section},$$

and therefore

$$\text{lateral surface}=2\pi r_2\times l=2\pi\times\tfrac{1}{2}(r_1+r_3)\times l=\pi l(r_1+r_3),$$

and
$$\text{whole surface}=\pi r_1^2+\pi l(r_1+r_3)+\pi r_3^2$$

If h, the altitude of the frustum, be given, we have

$$l=\sqrt{h^2+(r_1-r_3)^2}$$

C *The Sphere*

§ 86 *Surface of a Spherical Zone* —Let AB (fig 52) be a small arc of the sphere, and let AA, BB be perpendicular to the axis XX, to find the surface of the zone generated by the arc AB Join AB, and draw OP perpendicular to AB BD parallel to XX′, and PP′ parallel to AA′ or BB The chord AB generates the frustum of a cone, whose lateral surface $=2\pi$PP × AB

But, since the triangles ABD and OPP are similar,

$$\frac{AB}{BD}=\frac{OP}{PP},$$

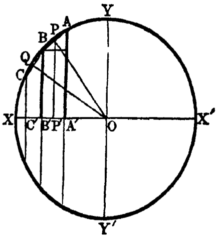


Fig 52

therefore area of conical frustum $=2\pi$ OP BD $=2\pi$ OP A B

Similarly the area of the frustum generated by BC $=2\pi$ OQ B C′

But in the limit when the chords AB, BC &c, are indefinitely diminished, the perpendiculars OP, OQ &c become each $=r$, and hence by summing all the areas we get in the limit

$$\text{area of zone}=2\pi r\times(\text{projection of arc on axis of revolution})$$

Hence the convex surface of a segment of a sphere is equal to the circumference of a great circle multiplied by the height of the segment or zone

§ 87 *Surface of a Sphere* —The whole sphere being a zone whose height is $2r$, we obtain at once

$$\text{surface of sphere}=2\pi r\times 2r=4\pi r^2,$$

or the surface of a sphere is equal to four great circles

The total surface of the cylinder circumscribing the sphere of radius r is $6\pi r^2$, hence the surface of the sphere $=\tfrac{2}{3}$ surface of circumscribing cylinder

§ 88 *Surface of a Lune, a Spherical Triangle, and a Spherical Polygon.*—It is shown in spherical trigonometry that

(α) the area of a lune included between two great circles of a sphere of radius r, and whose inclination is θ radians, is

$$2\theta r^2,$$

(β) the area of a spherical triangle whose angles are A, B, C is

$$(A+B+C-\pi)r^2,$$

(γ) the area of a spherical polygon of r sides is

$$\{P-(r-2)\pi\}r^2,\ \text{where P is the sum of its angles}$$

§ 89 *Measurement of Solid Angles* —A convenient unit for the measurement of plane angles is the "radian" If we assume that each unit of surface of a sphere subtends the same solid angle at the centre, we can deduce a very convenient unit for the measurement of solid angles This unit, which has received the name "steradian," we define to be the solid angle subtended at the centre of a sphere by a portion of the surface whose area is r^2

§ 90 *Number of Steradians in an Angle* —Let A be the angle at the centre of a sphere, and let S be the portion of the surface of the sphere which it intercepts, then

$$\frac{\text{number of steradians in A}}{1}=\frac{S}{r^2}$$

For example, if A be a plane solid angle S = a hemisphere $=2\pi r^2$, hence the number of steradians in a plane solid angle $=\frac{S}{r^2}=\frac{2\pi r^2}{r^2}=2\pi$ and therefore the number of steradians in the solid angle at a point $=4\pi$ This solid angle is sometimes called a steregon

Hence, if we can find the surface subtended by any solid angle, we can always find its magnitude in terms of the unit solid angle

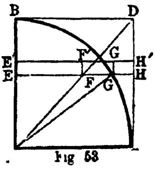


Fig 53

§ 91 *Volume of a Sphere* —Let ABC (fig 53) be the quadrant of a circle, draw DB and DC tangents to it, then, if AD be joined and the whole figure be conceived as rotating round AB, ABD ABC and ABDC will generate a cone, a hemisphere and a cylinder respectively

Now draw two parallel planes EFGH and F F G H very near each other and perpendicular to AB, and draw FF and GG parallel to AB then, by § 80,

volume generated by EHH E $=\pi\text{EH}^2\times\text{EE}$,
„ „ EGG E $=\pi\text{EG}^2\times\text{EE}$,
„ EFF E $=\pi\text{EF}^2\times\text{EE}$

Thus volume generated by EFF E + volume generated by EGG E

$$=\pi(\text{EF}^2+\text{EG}^2)\times\text{EE}=\pi(\text{EA}^2+\text{EG}^2)\times\text{EE}$$
$$=\pi(\text{AG}^2)\times\text{EE}=\pi\text{EH}^2\times\text{EE}$$
$$=\text{volume generated by EHH E}$$

Therefore in the limit when the number of slices is indefinitely increased and their thickness indefinitely diminished we have volume of cone generated by AF + volume of spherical zone generated by CG = volume of cylinder generated by CH

Let r = radius of sphere h = AE = height of zone ACGE then

volume of cone $=\frac{1}{3}\pi h^2\times h=\frac{1}{3}\pi h^3$, and

volume of cylinder $=\pi r^2\times h$

therefore volume of spherical zone $=\pi r^2h-\frac{1}{3}\pi h^3$
$=\frac{1}{3}\pi h(3r^2-h^2)$

The height of a hemisphere is r

therefore volume of hemisphere $=\frac{1}{3}\pi r(3r^2-r^2)=\frac{2}{3}\pi r^3$

and volume of whole sphere $=\frac{4}{3}\pi r^3$

a result readily obtainable by the infinitesimal calculus or by inscribing within the sphere a series of triangular pyramids whose vertices all meet at the centre of the sphere and the angles of whose bases all rest on the surface In the limit the altitude of each pyramid becomes the radius of the sphere and the sum of the bases of the pyramids the surface of the sphere, hence

$$\text{volume}=\tfrac{1}{3}\text{S}\times r=\tfrac{1}{3}\times 4\pi r^2\times r=\tfrac{4}{3}\pi r^3$$

The volume of the circumscribing cylinder $=\pi r^2\times 2r=2\pi r^3$, therefore volume of sphere $=\frac{2}{3}$ volume of circumscribing cylinder

§ 92 Let S denote the surface of a sphere and V its volume, then from §§ 87 and 91 we have

$$(\alpha)\ r=\frac{\sqrt{\text{S}}}{2\sqrt{\pi}}=\sqrt[3]{\frac{3}{4\pi}}\times\sqrt{\text{V}},$$
$$(\beta)\ \text{S}=\sqrt{\pi(6\text{V})},$$
$$(\gamma)\ \text{V}=\frac{1}{6\sqrt{\pi}}\sqrt{(\text{S})^3},$$

formulæ which give the radius in terms of the surface or volume, the surface in terms of the volume, and the volume in terms of the surface

§ 93 *Volume of a Spherical Shell* —Let r and r_1 denote the radii of the two spheres then

$$\text{volume of shell}=\text{V}=\tfrac{4}{3}\pi r_1^3-\tfrac{4}{3}\pi r^3$$
$$=\tfrac{4}{3}\pi(r_1^3-r^3)$$
$$=\tfrac{4}{3}\pi(r_1-r)(r_1^2+r_1r+r^2)$$

Now let $r_1-r=h$, then

$$\text{V}=\tfrac{4}{3}\pi r_1^2h\left(1+\frac{r}{r_1}+\frac{r^2}{r_1^2}\right)$$

If h be small compared with r_1 then r/r_1 is very nearly equal to 1, and we have approximately

$$\text{V}=\tfrac{4}{3}\pi r_1^2h(1+1+1)=4\pi r_1^2h$$

Again, if h be nearly equal to r_1 r is very small and r/r_1 is also very small, so that we have approximately

$$\text{V}=\tfrac{4}{3}\pi r_1^2h$$

§ 94 *Volume of a Spherical Segment* —Let CRC (fig 54) be a section of a spherical segment whose altitude RQ is p, then, if OQ $=h$, volume of segment CRC = volume of hemisphere − volume of zone AA C′C

$$=\tfrac{2}{3}\pi r^3-\tfrac{1}{3}\pi h\{3r^2-h^2\},\ \S\ 91$$
$$=\tfrac{2}{3}\pi r^3-\tfrac{1}{3}\pi(r-p)\{3r^2-(r-p)^2\}$$
$$=\tfrac{1}{3}\pi p^2(3r-p)$$

If we put $p=2r$, we obtain as before volume of sphere $=\frac{4}{3}\pi r^3$

Again if CQ $=a_1$ we have

$$\text{CQ}^2=a_1^2=\text{RQ R Q}=p(2r-p),$$

whence $r=\dfrac{a_1^2+p^2}{2p}$,

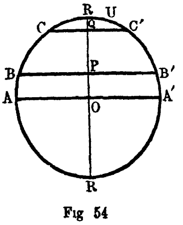


Fig 54

therefore volume of segment $=\frac{1}{6}\pi p(3a_1^2+p^2)$

§ 95 *Volume of a Spherical Frustum* —When one of the terminating planes passes through the centre we have already found that the volume

$$=\tfrac{1}{3}\pi h(r^2-h^2),$$

where h is its altitude

Now suppose that neither of the terminating planes passes through the centre, for example, to find the volume of the frustum BB C′C.

Let RQ $=p$ and RP $=q$, then

$$\text{BB C C}=\text{segment RBB}-\text{segment RCC}'$$
$$=\tfrac{1}{6}\pi q(3a_2^2+q^2)-\tfrac{1}{6}\pi p(3a_1^2+p^2),$$

where a_1 and a_2 are the radii of the ends CC and BB′

Let $q-p=h$ = height of frustum, and, since, from the geometry of the figure,

$$\frac{a_1^2+p^2}{p}=\frac{a_2^2+q^2}{q}=2r,$$

we have $\text{volume}=\frac{1}{6}\pi h\{3(a_1^2+a_2^2)+h^2\}$,

a result which may also be obtained by considering BB′C C as the difference of the two zones AA C C and AA B B

D *Spheroid*

§ 96 *Surface of a Prolate Spheroid* —The prolate spheroid is the solid generated by the revolution of an ellipse about its major axis. If S be the surface generated by an arc of the curve, then

$$\text{S}=2\pi\int y\sqrt{1+\left(\frac{dy}{dx}\right)^2}\,dx,\ \text{taken between proper limits}$$

In the case before us

$$\text{S}=2\pi b^2+2\pi\frac{ab}{e}\sin^{-1}e,$$

where e is the eccentricity (INFINITESIMAL CALCULUS, art 179)

§ 97 *Surface of an Oblate Spheroid* —The oblate spheroid is the solid generated by the revolution of an ellipse about its minor axis (fig 55)

Here surface $=2\pi a^2+\pi\dfrac{b^2}{e}\log_e\dfrac{1+e}{1-e}$ (INFINITESIMAL CALCULUS, art 179)

§ 98 *Volume of a Spheroid* —We have volume of prolate spheroid

$$=\pi\int_{-a}^{+a}b^2\left(1-\frac{x^2}{a^2}\right)dx=2\pi b^2\int_0^a\left(1-\frac{x^2}{a^2}\right)dx=\tfrac{4}{3}\pi ab^2.$$

Similarly volume of oblate spheroid $=\frac{4}{3}\pi a^2b$

Thus,

$$(\alpha)\quad\frac{\text{volume of prolate spheroid}}{\text{volume of oblate spheroid}}=\frac{\frac{4}{3}\pi ab^2}{\frac{4}{3}\pi a^2b}=\frac{b}{a},$$
$$(\beta)\quad\frac{\text{sphere described on major axis}}{\text{prolate spheroid}}=\frac{\frac{4}{3}\pi a^3}{\frac{4}{3}\pi ab^2}=\frac{a^2}{b^2};$$
$$(\gamma)\quad\frac{\text{sphere described on minor axis}}{\text{oblate spheroid}}=\frac{\frac{4}{3}\pi b^3}{\frac{4}{3}\pi a^2b}=\frac{b^2}{a}$$

§ 99 *Volume of a Segment of a Spheroid*

(α) *The prolate spheroid* —This segment is generated by the revolution of AMP (fig 23, p 20) about AM, and hence

$$\text{its volume}=\pi\int_0^h y^2dx=\pi\frac{b^2}{a^2}\int_0^h(2ax-x^2)dx=\frac{\pi}{3}\times\frac{b^2h^2}{a^2}(3a-h),$$

where A is the origin and AM $=h$

(β) *The oblate spheroid* —The segment in this case is generated by the revolution of BMP (fig 55) about BC, and hence

$$\text{its volume}=\pi\int_0^h y^2dx=\pi\frac{a^2}{b^2}\int_0^h(2bx-x^2)dx=\frac{\pi}{3}\times\frac{a^2h^2}{b^2}(3b-h),$$

where B is the origin and BM $=h$

§ 100 *Volume of the Frustum of a Spheroid when one of the Terminating Planes passes through the Centre*

(α) *The prolate spheroid* —The frustum in this case is generated by the revolution of BCMP about CM (fig 23)

Now volume generated by BCMP
= volume generated by BCA
− volume generated by PMA

$$=\tfrac{2}{3}\pi ab^2-\frac{\pi}{3}\times\frac{b^2h^2}{a^2}(3a-h)$$
$$=\frac{\pi}{3}\times\frac{b^2k}{a}(3a^2-k^2),\ \text{where}$$

k = CM = height of frustum $=a-h$

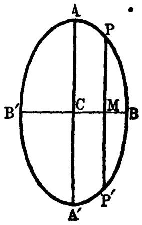


Fig 55

(β) *The oblate spheroid* —We can show in a similar manner that the volume generated in this case

$$=\frac{\pi}{3}\times\frac{a^2k}{b^2}(3b^2-k^2)$$

The above formulæ may be put into another form Thus, in the case of the prolate spheroid, since the point P lies on the ellipse $b^2x^2+a^2y^2=a^2b^2$, we have

$$b^2k^2+a^2b_1^2=a^2b^2,\ \text{where}\ b_1=\text{PM},\ \text{which gives}$$

$$k^2=a^2\frac{(b^2-b_1^2)}{b^2},$$

whence, by substitution, the volume of prolate frustum

$$=\tfrac{1}{3}\pi k(2b^2+b_1^2)$$

Similarly we can show that the volume of the oblate frustum

$$=\tfrac{1}{3}\pi k(2a^2+a_1^2),$$

where $a_1 = \mathrm{PM}$

These formulæ play an important part in the gauging of casks

E *Paraboloid*

§ 101 *Surface of a Paraboloid* —Let the equation to the parabola be $y^2=4ax$, and let the coordinates of P (fig 21, p 19) be x_1, y_1, then the surface of the paraboloid generated by the revolution of AM about AP

$$=2\pi\int_0^{x_1} y\sqrt{1+\left(\frac{dy}{dx}\right)^2}dx=4\pi\sqrt{a}\int_0^{x_1}\sqrt{x}\;\sqrt{\frac{x+a}{x}}dx$$

$$=\tfrac{8}{3}\pi\sqrt{a}\left\{(x_1+a)^{\frac{3}{2}}-a^{\frac{3}{2}}\right\}$$

§ 102 *Volume of a Paraboloid* —With the same notation we have

$$\text{volume}=\pi\int_0^{x_1}y^2dx=4\pi a\int_0^{x_1}xdx=\tfrac{1}{2}\pi\times 4ax_1\times x_1=\tfrac{1}{2}\pi y_1^2\times x_1,$$

or the volume of a paraboloid generated by the revolution of a part of a parabola between the vertex and any point is equal to half the volume of the circumscribing cylinder

§ 103 If the coordinates of Q be x_2, y_2, then the volume of the frustum PP Q Q

$$=\tfrac{1}{2}\pi\left\{y_2^2x_2-y_1^2x_1\right\}=2\pi a(x_2^2-x_1^2)=\tfrac{1}{2}\pi(y_2^2+y_1^2)h,$$

where $h=\mathrm{MN}$, hence the volume of the frustum of a paraboloid is equal to half the sum of the areas of its ends multiplied by its height

F *Ellipsoid*

§ 104 *Volume of an Ellipsoid* —The equation to the ellipsoid being

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{z^2}{c^2}=1,$$

the equation to the elliptic section at the distance z from the origin is

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}=1-\frac{z^2}{c^2}$$

Now if we draw an indefinite number of parallel planes perpendicular to the axis of z each slice will be an infinitely thin cylindrical plate, and accordingly the whole volume of the ellipsoid

$$=\int \mathrm{A}dz,\ \text{where A is the area of the elliptic section}$$

But $\mathrm{A}=\pi ab\left(1-\frac{z^2}{c^2}\right)$, § 51,

therefore $\quad \text{volume}=\pi ab\int_{-c}^{c}\left(1-\frac{z^2}{c^2}\right)dz=\tfrac{4}{3}\pi abc$

The sphere being an ellipsoid whose axes are all equal, we obtain as before

$$\text{volume of sphere}=\tfrac{4}{3}\pi a^3=\tfrac{4}{3}\pi r^3$$

G *Hyperboloid*

§ 105 *Volume of an Hyperboloid* —The hyperboloid is generated by the revolution of the hyperbolic segment ANP about AN (fig 24, p 20) If the coordinates of P be x_1, y_1, then

$$\text{volume of hyperboloid}=\pi\int_a^{x_1}y^2\,dx=\pi\frac{b^2}{a^2}\int_a^{x_1}(x^2-a^2)dx$$

where $h=\mathrm{AN}=x_1-a$

Again, since x_1, y_1 is on the curve, we have

$a^2y_1^2-b^2(a+h)^2=-a^2b^2$, which gives $\frac{b^2}{a^2}=\frac{y_1^2}{2ah+h^2}$, whence

$$\text{volume of hyperboloid}=\frac{\pi hy_1^2}{3}\times\frac{3a+h}{2a+h}$$

H *Solids to which the "Prismoidal Formula" applies*

§ 106 It was shown in § 72 that the volume of any polyhedron bounded by two parallel planes and by plane rectilinear figures

$$=\tfrac{1}{6}h(\mathrm{A}_1+4\mathrm{A}_2+\mathrm{A}_3),$$

where A_1, A_3, and A_2 denote respectively the areas of the two ends and of the middle section

We now proceed to show that the same formula determines the volumes of all solids bounded by two parallel planes, provided the area of any section parallel to these planes can be expressed as a rational integral algebraic function of the third degree in x, where x is the distance of the section from either plane.

Let $\phi(x)=\mathrm{A}+\mathrm{B}x+\mathrm{C}x^2+\mathrm{D}x^3+\qquad+\mathrm{K}x^n$ denote the area of the section in question

Now the solid between the sections $\phi(0)$ and $\phi(4)$ is equal to the solid between the sections $\phi(0)$ and $\phi(2)$ plus the solid between the sections $\phi(2)$ and $\phi(4)$ Hence if the prismoidal formula is to hold in this case, we have

$$\tfrac{1}{6}h\left\{\phi(0)+4\phi(2)+\phi(4)\right\}$$

$$=\tfrac{1}{12}h\left\{\phi(0)+4\phi(1)+\phi(2)\right\}+\tfrac{1}{12}h\left\{\phi(2)+4\phi(3)+\phi(4)\right\},$$

where h is the distance between the sections $\phi(0)$ and $\phi(4)$. Hence we have

$$\phi(0)-4\phi(1)+6\phi(2)-4\phi(3)+\phi(4)=0.$$

Now

$$\begin{aligned}
\phi(0)&=\mathrm{A}\\
-4\phi(1)&=-4\mathrm{A}-4\mathrm{B}-4\mathrm{C}-4\mathrm{D}-4\mathrm{E}-\qquad-4\mathrm{K}\\
+6\phi(2)&=6\mathrm{A}+12\mathrm{B}+24\mathrm{C}+48\mathrm{D}+96\mathrm{E}+\qquad+6\,2^n\mathrm{K}\\
-4\phi(3)&=-4\mathrm{A}-12\mathrm{B}-36\mathrm{C}-108\mathrm{D}-324\mathrm{E}-\qquad-4\,3^n\mathrm{K}\\
+\ \phi(4)&=\mathrm{A}+4\mathrm{B}+16\mathrm{C}+64\mathrm{D}+256\mathrm{E}+\qquad+4^n\mathrm{K}
\end{aligned}$$

Therefore $\quad 0=0+0+0+0+24\mathrm{E}+\mathrm{PF}+\ .\ \ .\quad+\mathrm{TK}$

Hence $\mathrm{E}=\mathrm{F}=\qquad\mathrm{K}=0$, and therefore $\phi(x)$ must be a function of the third degree in order that the prismoidal formula may apply

§ 107 If we take $\phi(x)=\mathrm{A}+\mathrm{B}x+\mathrm{C}x^2+\mathrm{D}x^3$, there will be as many possible varieties as there are combinations of four things, one, two, three, and four together, *i e*, $2^4-1=15$ varieties Corresponding to each of these there will be *at least one solid* the area of a section of which at a distance x from one of the parallel planes is $\phi(x)=\mathrm{A}+\mathrm{B}x+\mathrm{C}x^2+\mathrm{D}x^3$, and *at least one solid of revolution* generated by the curve whose equation is of the form

$$\pi y^2=\phi(x)=\mathrm{A}+\mathrm{B}x+\mathrm{C}x^2+\mathrm{D}x^3$$

As space prevents us discussing all the cases that may arise, we content ourselves by giving three examples as illustrations.

(α) *Volume of an ellipsoid* —Here $\phi(x)=\mathrm{B}x+\mathrm{C}x^2$

Let $2a$, $2b$, and $2c$ be the axes of which $2a$ is the greatest, then $h=2a$, $\mathrm{A}_1=0$, $\mathrm{A}_3=0$, and $\mathrm{A}_2=\pi bc$,

therefore $\quad \text{volume}=\tfrac{1}{6}h(\mathrm{A}_1+4\mathrm{A}_2+\mathrm{A}_3)=\tfrac{1}{3}a(4\pi bc)=\tfrac{4}{3}\pi abc$,

which agrees with the result in § 104

(β) *Volume of a sphere* —Here $\pi y^2=\phi(x)=\mathrm{B}x+\mathrm{C}x^2$

Let r be the radius of the sphere, then $h=2r$, $\mathrm{A}_1=0$, $\mathrm{A}_3=0$, and $\mathrm{A}_2=\pi r^2$, hence, as before (§ 91)

$$\text{volume of sphere}=\tfrac{1}{6}h(\mathrm{A}_1+4\mathrm{A}_2+\mathrm{A}_3)=\frac{2r}{6}(4\pi r^2)=\tfrac{4}{3}\pi r^3$$

(γ) *Volume of a right circular cone* —Here $\pi y^2=\phi(x)=\mathrm{C}x^2$

Let r = radius of base and h the altitude, then $\mathrm{A}_1=0$, $\mathrm{A}_3=\pi r^2$, and $\mathrm{A}_2=\pi(\tfrac{1}{2}r)^2$, hence

$$\text{volume of cone}=\tfrac{1}{6}h\left\{\mathrm{A}_1+4\mathrm{A}_2+\mathrm{A}_3\right\}=\tfrac{1}{6}h\left\{\pi r^2+\pi r^2\right\}=\tfrac{1}{3}h\pi r^2$$

In a similar manner we can determine the volumes of a cylinder, a prolate spheroid, an oblate spheroid, &c

§ 108 In general, if in any solid we have

$$\phi(x)=\mathrm{A}+\mathrm{B}x+\mathrm{C}x^2+\mathrm{D}x^3,$$

where A, B, C, and D are known constants, then, if h be the length of the solid,

$$\begin{aligned}
\mathrm{A}_1&=\phi(0)=\mathrm{A},\\
\mathrm{A}_2&=\phi(\tfrac{1}{2}h)=\mathrm{A}+\mathrm{B}(\tfrac{1}{2}h)+\mathrm{C}(\tfrac{1}{2}h)^2+\mathrm{D}(\tfrac{1}{2}h)^3,\\
\mathrm{A}_3&=\phi(h)=\mathrm{A}+\mathrm{B}h+\mathrm{C}h^2+\mathrm{D}h^3,
\end{aligned}$$

and therefore

$$\begin{aligned}
\text{volume of solid}&=\tfrac{1}{6}h(\mathrm{A}_1+4\mathrm{A}_2+\mathrm{A}_3)\\
&=\mathrm{A}h+\tfrac{1}{2}\mathrm{B}h^2+\tfrac{1}{3}\mathrm{C}h^3+\tfrac{1}{4}\mathrm{D}h^4.
\end{aligned}$$

I *Solids of Revolution in General*

§ 109 *Volume of any Solid of Revolution* —Let $\mathrm{P}_1\mathrm{P}_2\quad .\quad\mathrm{P}_n$ (fig 34) be the generating curve, and $\mathrm{A}_1\qquad\mathrm{A}_n$ the axis of revolution Divide the curve into portions in the points P_2, P_3, &c, and draw the chords and tangents of the small arcs $\mathrm{P}_1\mathrm{P}_2$, $\mathrm{P}_2\mathrm{P}_3$, &c, then it is evident that the solid generated by the curve is greater than the sum of the conical frusta traced out by the chords and less than the sum of the conical frusta traced out by the tangents. Hence, by increasing the number of chords, namely, by increasing the points of division of the curve, we can make the difference between these sums as small as we please, and therefore by this method we can approximate as closely as we please to the volume of the solid generated

Assuming that the points P_1, P_2, P_3 are so near each other that the solid generated differs little from the frustum of a cone, and using the same notation as in § 63, we have volume generated by

$$\begin{aligned}
\mathrm{P}_1\mathrm{P}_2\mathrm{P}_3&=\tfrac{1}{6}\pi\mathrm{A}_1\mathrm{A}_3(s_1^2+4s_2^2+s_3^2)=\tfrac{1}{6}\pi 2\mathrm{A}_1\mathrm{A}_2(s_1^2+4s_2^2+s_3^2)\\
&=\tfrac{1}{3}\pi a(s_1^2+4s_2^2+s_3^2),
\end{aligned}$$

similarly the volume generated by

$$\mathrm{P}_3\mathrm{P}_4\mathrm{P}_5=\tfrac{1}{3}\pi a(s_3^2+4s_4^2+s_5^2),$$

whence the volume generated by the whole curve $\mathrm{P}_1\mathrm{P}_2\qquad\mathrm{P}_n$

$$=\tfrac{1}{3}\pi a\left\{s_1^2+s_n^2+2(s_3^2+s_5^2+\qquad+s_{n-2}^2)+4(s_2^2+s_4^2+\ .\qquad+s_{n-1}^2)\right\};$$

or (since $\pi s_1^2 = \frac{c_1^2}{4\pi}$, $\pi s_2^2 = \frac{c_2^2}{4\pi}$, &c)

$$= \frac{1}{\pi}\frac{a}{12}\{c_1^2+c_n^2+2(c_3^2+c_5^2+ \quad +c_{n-2}^2)+4(c_2^2+c_4^2+ \quad +c^2_{n-1})\},$$

a formula more convenient in practice, as it is sometimes more easy to measure equidistant circumferences than equidistant radii

J *Theorems of Pappus*

§ 110 The following general propositions concerning surfaces and solids of revolution, usually called Guldin s theorems are worth the reader s attention

If any plane curve revolve about any external axis situated in its plane, then

(α) the surface of the solid which is thereby generated is equal to the product of the perimeter of the revolving curve and the length of the path described by the centre of gravity of that perimeter,

(β) the volume of the solid is equal to the product of the area of the revolving curve and the length of the path described by the centre of gravity of the revolving area

We content ourselves with an example or two of the application of these theorems, referring to the article INFINITESIMAL CALCULUS for the proofs

Example 1 —To find the surface and volume of a circular ring —Let a be the distance of the centre of the generating curve, in this case a circle, from the axis of rotation and r the radius of the circle, then

$$\text{perimeter of generating curve} = 2\pi r,$$
$$\text{area of generating curve} = \pi r^2, \text{ and}$$

path described by the centre of gravity either of the perimeter or area $=2\pi a$, hence

$$\text{surface of ring} = 2\pi r \times 2\pi a = 4\pi^2 ra, \text{ and}$$
$$\text{volume of ring} = \pi r^2 \times 2\pi a = 2\pi^2 r^2 a$$

Example 2 —To find the volume swept out by an ellipse whose axes are $2a$ and $2b$, revolving about an axis in its own plane whose distance from the centre of the ellipse is c

Here area of generating curve $=\pi ab$

and path described by centre of gravity of area $=2\pi c$, hence

$$\text{volume generated} = \pi ab \times 2\pi c = 2\pi^2 abc$$

Example 3 —A circle of r inches radius with an inscribed regular hexagon, revolves about an axis a inches distant from its centre, and parallel to a side of the hexagon to find the difference in area of the generated surfaces and volumes

$$\begin{aligned} \text{Here perimeter of circle} &= 2\pi r \\ \text{and perimeter of hexagon} &= 12 \times r \sin 30^\circ \ (\S\ 17) \\ &= 6r \\ \text{also area of circle} &= \pi r^2 \\ \text{and area of hexagon} &= 3r^2 \sin 60^\circ \ (\S\ 18\ \beta) \\ &= \tfrac{3}{2}\sqrt{3}r^2, \end{aligned}$$

hence difference of surfaces generated

$$= 4\pi^2 ra - 12\pi ar = 4\pi ar(\pi - 3),$$

and difference of volumes generated

$$\begin{aligned} &= 2\pi^2 r^2 a - 3\pi r^2 \sqrt{3}a \\ &= \pi r^2 a(2\pi - 3\sqrt{3}) \end{aligned}$$

PART III GAUGING

§ 111 By gauging is meant the art of measuring the volume of a cask, or any portion of it The subject is one of great interest and practical importance, but space will only permit us to discuss it very briefly If the cask whose capacity we wish to determine be a solid of revolution, then its volume can at once be computed, either exactly or approximately, by the methods already described

It is usual to divide casks into the following four classes according to the nature of the revolving curve —

(α) the middle frustum of a spheroid,
(β) the middle frustum of a parabolic spindle,
(γ) two equal frusta of a paraboloid, united at their bases,
(δ) two equal frusta of a cone, united at their bases

Casks of the second, third, and fourth variety are rarely met with in practice, and we shall accordingly confine our attention to the first kind which is considered the true or model form of cask

Let ABCD (fig 56) be a section of the cask, and assume it to be the middle *frustum of a prolate spheroid*, then

$$\text{its volume} = \tfrac{1}{3}\pi(2b^2 + b_1^2)k,$$

where $b = \text{OY}$, $b_1 = \text{AX}$, and $k = \text{XX}'$ (§ 99)

YY is called the bung diameter, and AB or CD the head diameter

An imperial gallon contains 277 274 cubic inches and therefore the number of gallons in the above cask

$$= \frac{\pi(2b^2+b_1^2)k}{3 \times 277\ 274} = \frac{\pi}{831\ 822}(2b^2+b_1^2)k$$
$$= \left(\frac{2d^2+d_1^2}{1059\ 1}\right)k, \text{ where } d = 2b,\ d_1 = 2b_1$$

whence we have the rule —to the square of the head diameter add twice the square of the bung diameter, multiply the sum by the length and divide the result by 1059 1, and the answer is the content in imperial gallons

Casks as ordinarily met with are not true spheroidal frusta, but it is better to consider them as such, calculate their capacity on this assumption, and then make allowance for the departure from the spheroidal form The determination of the proper allowance to be made in each case is a matter depending on the skill and experience of the gauger, and proficiency in the art can only be attained by considerable practice

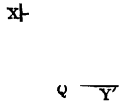


Fig 56

§ 112 If the cask be very little curved, we obtain an approximation to its capacity by considering it as made up of two equal frusta of a cone, united at their bases Hence from § 83 we have

$$\text{volume of cask} = \tfrac{1}{3}\pi h(r_1^2 + r_1 r_3 + r_3^2) \text{ nearly}$$

Here we neglect the small volumes generated by APY, YSD, BQY, and YRC and therefore the volume is too small

If we put $r_1 r_3 = r_1^2$ we obtain

$$\text{volume} = \tfrac{1}{3}\pi h(2r_1^2 + r_3^2),$$

which is a little too large and therefore the true volume lies between these two limits and a very close approximation to it is said to be given by the formula

$$\tfrac{1}{3}\pi h\{2r_1^2 + r_3^2 - \tfrac{2}{5}(r_1^2 - r_3^2)\}$$

§ 113 *Ullage of a Cask* —The quantity of liquor contained in a cask partially filled and the capacity of the portion which is empty are termed respectively the wet and dry ullage

(α) *Ullage of a standing cask* —By means of the method applied in § 105, the following rule is deduced —

Add the square of the diameter at the surface the square of the diameter at the nearest end, and the square of double the diameter half way between, multiply the sum by the length between the surface and the nearest end, and by 000472

The product will be the wet or dry ullage according as the lesser portion of the cask is filled or empty

(β) *Ullage of a lying cask* —The ullage in this case is found approximately on the assumption that it is proportional to the segment of the bung circle cut off by the surface of the liquor The rule adopted in practice is

$$\text{ullage} = \tfrac{3}{2}\text{ content} \times \text{segmental area} \qquad \text{(W T *)}$$

MENTAL DISEASES See INSANITY

MENTON (Ital, *Mentone*), a cantonal capital in the department of Alpes Maritimes, France, situated 15 miles north-east of Nice, on the shores of the Mediterranean The town, which has a population of about 8000, rises like an amphitheatre on a promontory by which its semicircular bay (5 miles wide at its entrance, and bounded on the W by Cape Martin and on the E by the cliffs of La Murtola) is divided It s composed of two very distinct part one below along the sea shore is the town of hotels and of foreigners, which alone is accessible to wheeled vehicles, above is that of the native Mentonese, with steep, narrow, and dark streets, spread over and clinging to the mountain, around the strong castle which was once its protection against the attacks of pirates Facing the south-east, and sheltered on the north and west by high mountains, the Bay of Menton enjoys a delicious climate, and is on this account much frequented by invalids requiring a mild and equable temperature The mean for the year is 61° Fahr, exceeding that of Rome or of

Pisa, and equalling that of Naples Frost occurs on the average only once in ten years, in one particular year the thermometer did not fall below 46° Fahr In summer the heat is never very great, the temperature rarely exceeding 86° Fahr Winter and summer are the most agreeable seasons, in autumn the rain storms are accompanied by sudden changes of temperature, and in spring the sea breezes are apt to be violent Besides the charms of its climate, Menton offers those of an almost tropical vegetation Lemon trees, olive-trees, and pines, rising above each other in successive stages, adorn the surrounding slopes The district produces forty millions of lemons yearly, and this is the principal source of its natural wealth The olive trees are remarkable for the great size they have attained in the course of the centuries during which they have continued to bear Of their wood a multitude of fancy objects are made for sale to strangers

The origin of Menton is unknown During the Middle Ages it was successively occupied by the Saracens, the Genoese, and the princes of Anjou In the middle of the 14th century it was purchased as a single domain by the Grimaldis, lords of Monaco During the times of the republic and the first empire it belonged to France, but in 1815 it again became the property of the princes of Monaco, who subjected it to such exactions that in 1848 its inhabitants, weary of finding their reasonable demands put off with empty promises, proclaimed their town free and independent, under the protection of Sardinia Menton, with the neighbouring commune of Roquebrune, was united to France in 1860, at the same time as Nice and Savoy

MENTZ See Mainz

MENZEL, Wolfgang (1798–1873), poet, critic, and historian, was born June 21, 1798, at Waldenburg in Silesia, studied at Breslau, Jena, and Bonn, and after living for some time in Aarau and Heidelberg finally settled in Stuttgart, where, from 1830 to 1838, he had a seat in the Wurtemberg "landtag" His first work, a clever and original volume of poems, entitled *Streckverse* (Heidelberg, 1823), was followed in 1824–25 by a popular *Geschichte der Deutschen* in three volumes, and in 1829 and 1830 by *Rubezahl* and *Narcissus*, the ballads upon which his reputation as a poet chiefly rests In 1851 he published the romance of *Furore*, a lively picture of the period of the Thirty Years' War, his other very numerous writings include *Geschichte Europa's*, 1789–1815 (1853), and histories of the German war of 1866 and of the Franco German war of 1870–71 From 1825 to 1848 Menzel edited a "Litteraturblatt" in connexion with the *Morgenblatt*, in the latter year he transferred his allegiance from the Liberal to the Conservative party, and in 1852 his "Literaturblatt' was again revived in that interest In 1866 his political sympathies again changed, and all his energies were employed to oppose the "particularism" of the Prussian "junkers" and the antiunionism of South Germany He died on April 23, 1873 His large private library of 18,000 volumes was afterwards acquired for the university of Strasburg

MEPHISTOPHELES, the name of one of the personifications of the principle of evil In old popular books and puppet-plays the word appears in various forms,—as Mephistopheles, Mephistophiles, Mephistophilis, and Mephostophilis In the *Tragical History of Doctor Faustus*, Marlowe writes "Mephistophilis", in the *Merry Wives of Windsor* we find "Mephistophilus' The etymology of the word is uncertain According to one theory, it may be taken to represent μηφωστοφίλης, in which case the meaning would be "one who loves not light" Another theory is that the word is a combination of the Latin "mephitis" and the Greek φίλος, signifying "one who loves noxious exhalations" Probably it is of Hebrew origin,—from מפיר, a destroyer, and טפל, taken to mean a liar This view is supported by the fact that almost all the names of devils in the magic books of the 16th century spring from the Hebrew In the old Faust legends the character of Mephistopheles is simply that of a powerful and wicked being who fulfils Faust's commands in order to obtain possession of his soul Marlowe attributes to him a certain dignity and sadness, and there can be little doubt that the Mephistophilis of the *Tragical History* suggested some important traits of Milton's Satan The name has been made famous chiefly by Goethe, whose conception of the character varied at different periods of his career In the fragment of *Faust* published in 1790, but written many years before, Mephistopheles has a clearly marked individuality, he is cynical and materialistic, but has a man's delight in activity and adventure, and his magical feats alone remind us that he is preternatural In revising and extending this fragment, which forms the chief portion of the first part of *Faust*, Goethe treated Mephistopheles as the representative of the evil tendencies of nature, especially of the tendency to denial for its own sake, rather than as a living person This character Mephistopheles maintains in the second part, where, indeed, the name often stands for a pure abstraction

See Julius Mosen, *Faust*, Duntzer, *Erlauterungen zu Goethe's Werken Faust*, Vischer, *Goethe's Faust*

MEQUINEZ (the Spanish form of the Arabic *Miknása*), a town of Morocco, the ordinary residence of the emperor, is situated in a fine hilly country about 70 miles from the west coast and 35 west-south west of Fez on the road to Sallee, in 34° N lat and 5° 35 W long The town wall, with its four-cornered towers, is kept in good condition, and a lower wall of wider circuit protects the luxuriant gardens with which the outskirts are embellished In the general regularity of its streets, and in the fairly substantial character of its houses, Mequinez ranks higher than any other town in Morocco, but it possesses few buildings of any note, except the palace, and the mosque of Mulei Ismael, which serves as the royal burying place At one time the palace (founded in 1634) was an imposing structure, but the finest part has been allowed to go to ruin In 1721 Windhus described it as "about 4 miles in circumference, the whole building exceeding massy, and the walls in every part very thick, the outward one about a mile long and 25 feet thick" The best part consisted of oblongs enclosing large open courts or gardens Mortar or concrete was the principal material used for the walls, but the pillars were in many cases marble blocks of great beauty and costliness (*A Journey to Mequinez*, London, 1725) Most of the inhabitants of Mequinez are connected more or less directly with the court Their number has been very variously estimated by different travellers Gråberg de Hemso gives 56,000 in 1834, Rohlfs in 1861 from 40,000 to 50,000, and Conring in 1680 about 30,000 The town was formerly called Tákarart Edrisi refers the present name to a Berber chief Meknás

MERAN, a favourite health resort, and the capital of a district in South Tyrol, Austria, is picturesquely situated at the foot of the vine clad Kuchelberg, on the right bank of the Passer, about half a mile above its junction with the Adige, and 45 miles to the south of Innsbruck Meran proper consists mainly of one long narrow street, called the Laubengasse, flanked by covered arcades In a wider sense, the name is often used to include the adjacent villages of Untermais, Obermais, and Gratsch The most noteworthy buildings are the Gothic church of St Nicholas, with its lofty tower, dating from the 14th and 15th centuries, the Spitalkirche, built in the 15th century, and restored in 1880, and the quaint old Furstenhaus, or residence of the counts of Tyrol The town contains a gymnasium, a nunnery and school for girls, an institution for sick priests, and several other charitable establishments

Meran owes its high reputation as a resort for consumptive and nervous invalids to the purity of its air and its comparative immunity from wind and rain in winter It stands in 46° 41′ N lat, at a height of 1050 feet above the sea, and has a mean annual temperature of about 54° Fahr Meran enjoys three seasons, being also visited in spring for the whey-cure and in autumn for the grape cure The arrangements for the comfort of the visitors are very complete, and the environs afford opportunity for numerous pleasant walks and excursions The favourite promenade of the inhabitants is on a massive dyke, built to protect the town against the encroachments of the Passer Nearly twenty old castles and chateaus are visible from the bridge over the Passer, the most interesting being Schloss Tyrol, an ancient edifice which has given its name to the entire country Meran is now frequented by about 6500 patients and 8000 to 9000 passing travellers annually In 1880 its population, including Obermais and Untermais, amounted to 5334 souls

Meran is probably the representative of the Roman Urbs Majensis afterwards known as Mairania It became a town in 1290 and down to 1490 was the capital of the counts and dukes of Tyrol The town suffered somewhat during the Peasants War in the 16th century, and subsequently from destructive floods As a health resort it has been known for about forty years The whole region in which it lies is singularly rich in historic interest

Authorities—Beda Weber *Meran* Duringsfeld *Aus Meran* 1868 Noe *Der Fruhling von Meran* Stampfer *Chronik von Meran* 1867 and *Geschichte der Stadt Meran* 1872 Pirche *Meran als Klimatischer Kurort* 1870 Plant *Fuhrer durch Meran* 2d ed 1879 Knoblauch *Meran* 5th ed 1881

MERCATOR, GERARDUS (Latinized form of Gerhard Kramer) (1512–1594), mathematician and geographer, was born at Rupelmonde in Flanders, May 5, 1512 Having completed his studies at Louvain, he devoted himself to geography, and, after being for some time attached to the household of Charles V, he was appointed cosmographer to the duke of Juliers and Cleves in 1559, taking up his residence at Duisburg, where he died December 2, 1594 One of his earliest cartographical works was a terrestrial globe (1541), followed in 1551 by a celestial globe In 1552 he published a treatise *De usu annuli astronomici* (Louvain), and at Cologne in 1569 his *Chronologia, hoc est temporum demonstratio ab initio mundi usque ad Annum Domini* 1568, *ex eclipsibus et observationibus astronomicis, sacris quoque Bibliis*, &c In the same year was published the first map on Mercator's well known projection, with the parallels and meridians at right angles, for use in navigation At Cologne, in 1578, appeared his *Tabulæ geographicæ ad mentem Ptolemæi restitutæ et emendatæ* The work by which he is chiefly known is his atlas, published in 1594 at Duisburg, in folio, under the title of *Atlas, sive Cosmographicæ meditationes de fabrica mundi* It contains, besides the maps, cosmographical and other dissertations, some of the theological views in which were condemned as heretical, it was completed by Hondius in 1607 Several of the maps had been previously published separately, the atlas being delayed to allow Ortelius to complete his Mercator also published in 1592 a *Harmonia Evangeliorum*

MERCURIAL AIR PUMP This name is given to two distinct instruments, one of which is founded on statical, the other on hydrodynamical principles

1 *The Statical Pump*—The famous spiritualist Swedenborg was the first to conceive an air pump in which a mass of mercury, by being made to rise and fall alternately within a vertical vessel, should do the work which in the ordinary instrument is assigned to the piston He published a description of his pump in 1722, but it is questionable whether his design was ever realized Of numerous subsequent inventions the only one which, in fact, has survived is the admirably simple and yet efficient instrument first described in 1858, but constructed some time before, by H Geisler of Bonn, which at once, and justly, met with universal acceptance

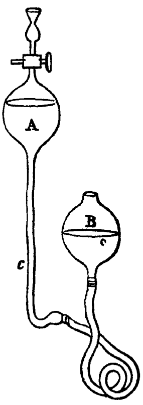


FIG 1—Geisler's Mercurial Air Pump

The general scheme of Geisler's pump is shown in fig 1 A and B are pear shaped glass vessels connected by a long narrow india rubber tube, which must be sufficiently strong in the body (or strengthened by a linen coating) to stand an outward pressure of 1 to 1½ atmospheres A terminates below in a narrow vertical tube *c*, which is a few inches longer than the height of the barometer, and to the lower end of this tube the india rubber tube is attached which connects A with B To the upper end of A is soldered a glass two-way stop-cock, by turning which the vessel A can either be made to communicate through *s* and a hole in the hollow cock with the vessel to be exhausted (I, fig 2), or through *g* with the atmosphere (II, fig 2), or can be shut off from both when the cock holds an intermediate position The apparatus, after having been carefully cleaned and dried, is charged with pure and dry mercury, which must next be worked backwards and forwards between A and B to remove all the air bells The air is then driven out of A by lifting B to a sufficient level, turning the cock into position II, and letting the mercury flow into A until it gets to the other side of the stop-cock, which is then placed in the intermediate position Supposing the vessel to be exhausted to have already been securely connected with *b*, we now lower the reservoir B so as to reduce the pressure in A sufficiently below the tension in the gas to be sucked in, and, by turning the cock into position I, cause the gas to expand into and almost fill A The cock is now shut against both *a* and *b*, the reservoir lifted, the gas contents of A discharged through *a*, and so on, until, when after an exhaustion mercury is let into A, the metal strikes against the top without interposition of a gas bell In a well made apparatus the pressure in the exhausted vessel is now reduced to $\frac{1}{10}$ or $\frac{1}{20}$ of a millimetre, or even less An absolute vacuum cannot be produced on account of the unavoidable air film between the mercury and the walls of the apparatus

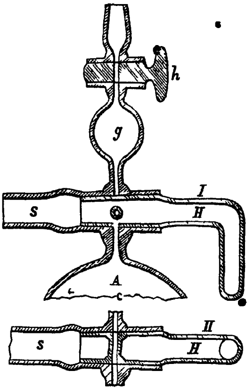


FIG 2—Arrangements of Stop Cock in Air Pump

The great advantage of the mercurial over the ordinary air-pump is that it evacuates far more completely than the latter, that it affords direct and unmistakable evidence of the exhaustiveness of its work, and—last not least—that it enables one to transfer the gas sucked out to another vessel without loss or contamination, so that it can be measured and analysed On account of this latter feature more especially, the instrument is highly valued as an auxiliary in gasometric researches Without it the researches on which rests our present knowledge of the gases of the blood could not have been carried out The actual instrument, as constructed for various kinds of work has of course various complexities of detail omitted in the above description For these the reader must refer to handbooks of practical physiology

As it takes a height of about 30 inches of mercury to balance the pressure of the atmosphere, a Geisler pump necessarily is a somewhat long legged and unwieldy instrument It can be considerably shortened, the two vessels A and B brought more closely together, and the somewhat objectionable india rubber tube be dispensed with, if we connect the air space in B with an ordinary air pump, and by means of it do the greater part of the sucking and the whole of the lifting work An instrument thus modified was constructed by Poggendorff (see his *Annalen*, vol cxxv p 151, 1865), and another, on somewhat different principles, by Prof Dittmar (see the "*Challenger Reports*)

Even a Geisler's stop cock requires to be lubricated to be absolutely gas tight, and this occasionally proves a nuisance Hence a number of attempts have been made to do without stop cocks altogether In Topler s pump[1] this is attained by using both for the inlet and the outlet vertical capillary glass tubes, soldered, the former to somewhere near the bottom, the latter to the top of the vessel These tubes, being more than 30 inches high, obviously act as efficient mercury traps , but the already considerable height of the pump is thus multiplied by two This consideration has led Alexander Mitscherlich (*Pogg Ann* , cl 420 1873), and quite lately F Neisen (*Z f Instrumentenkunde*, 1882, p 285) to introduce glass valves in lieu of stop cocks As glass floats on mercury, such valves do not necessarily detract from the exhaustive power of the pump

2 *The Dynamic Pump* —This was invented in 1865 by H Sprengel. The instrument, in its original (simplest) form (fig 3), consists of a vertical capillary glass tube *a* of about 1 mm bore, provided with a lateral branch *b* near its upper end, which latter, by an india rubber joint governable by a screw clamp, communicates with a funnel The lower end is bent into the shape of a hook, and dips into a pneumatic trough The vessel to be exhausted is attached to *b*, and, in order to extract its gas contents, a properly regulated stream of mercury is allowed to fall through the vertical tube Every drop of mercury, as it enters from the funnel, entirely closes the narrow tube like a piston and in going past the place where the side tube enters entraps a portion of air and carries it down to the trough, where it can be collected If the vertical tube, measuring from the point where the branch comes in, is a few inches greater than the height of the barometer, and the glass and mercury are perfectly clean, the apparatus slowly but surely produces an almost absolute vacuum

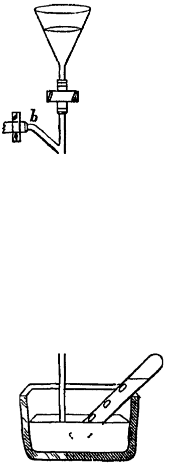


FIG 3 —Sprengel s Air Pump

The great advantages of Sprengel s pump lie in the simplicity of its construction and in the readiness with which it adapts itself to the collecting of the gas It did excellent service in the hands of Graham for the extraction of gases occluded in metals, and since then has become very popular in gas laboratories, especially in Britain Many improvements upon the original construction have been proposed One of these which deserves mention is to pass the mercury, before it enters the "falling tube through a bulb in which a good vacuum is maintained, by means of an ordinary air pump or a second "Sprengel (W D)

MERCURY was the Roman god who presided over barter, trade, and all commercial dealings His nature is probably more intelligible and simple than that of any other Roman deity His very name, which is connected with *merx*, *mercator*, &c , shows that he is the god of merchandise and the patron of merchants In the native Italian states no merchants and no trade existed till the influence of the Greek colonies on the coast introduced Greek customs into the cities of the land All the usages and terminology of trade, and all the religious ceremonies connected with it, were borrowed by the Romans from the Greeks It was no doubt under the rule of the Tarquins, when the prosperity of the state and its intercourse with the outer world were so much increased, that merchants began to ply their trade in Rome Doubtless the merchants practised their religious ceremonies from the first, but their god Mercurius was not officially recognized by the state till the year 495 B C Rome frequently suffered from scarcity of corn during the unsettled times that followed the expulsion of the Tarquins Various religious innovations were made to propitiate the gods , in 496 the Greek worship of Demeter, Dionysus, and Persephone was established in the city (see LIBER), and in 495 the Greek god HERMES (*q v*) was introduced into Rome under the Italian name of Mercurius (Livy, ii 21, 27) Preller thinks that at the same time the trade in corn was regulated by law, and a regular college of merchants was instituted This *collegium* was under the protection of the god , their annual festival was on the Ides of May, on which day the temple of the god had been dedicated at the southern end of the *circus maximus*, near the Aventine , and the members were called *mercuriales* as well as *mercatores* The Ides of May was chosen as the feast of Mercury, obviously because Maia was the mother of Hermes, *i e* , of Mercury (see MAIA) , and she was worshipped along with her son by the *mercuriales* on this day According to Preller, this religious foundation had a political object , it established on a legitimate and sure basis the trade between Rome and the Greek colonies of the coast, whereas formerly this trade had been exposed to the capricious interference of the Government officials for the year Like all borrowed religions in Rome, it must have retained the rites and the terminology of its Greek original (Festus, p 257) Mercury became the god, not only of the *mercatores* and of the corn trade, but of buying and selling in general , and it appears that, at least in the streets where shops were common, little chapels and images of the god were erected There was a spring dedicated to Mercury between his temple and the *Porta Capena* , every shopman drew water from this spring on the Ides of May, and sprinkled it with a laurel twig over his head and over his goods, at the same time entreating Mercury to remove from his head and his goods the guilt of all his deceits (Ovid, *Fasti*, v 673 *sq*) The art of the Roman tradesman was evidently like that of an Oriental tradesman in modern times, and the word *mercurialis* was popularly used as equivalent to "cheat ' In the Latin poets Mercury is often gifted with some of the manifold characters of the Greek Hermes, but this finer conception seems to have had no real existence in Roman religion

Roman statuettes of bronze in which Mercury is represented, like the Greek Hermes, standing holding the caduceus in the one hand and a purse in the other are exceedingly common The caduceus must have been introduced as a symbol of Mercury at a very early time, for it is found on Italian coins as early as the 4th century before Christ, and we learn that several were kept as sacred objects in the *adytum* of the sanctuary at Lavinium (Dion Hal , i 67) But its foreign origin is shown by the fact that, although it was a sign of peace, it was never borne by the *fetiales*, the old Italian heralds The very name is derived from the Greek κηρυκειον Preller s view (*Rom Myth*) that *mercuriales* and *mercatores* are the same guild is a tempting one but its truth is very doubtful Mommsen thinks that *mercuriales* were a purely local guild, viz , the *pagani* of the Circus valley

MERCURY, in chemistry, is a metal (symbol Hg) which is easily distinguished from all others by its being liquid at even the lowest temperatures naturally occurring in moderate climates To this exceptional property it owes the synonyms of *quicksilver* in English (with the Germans *quecksilber* is the only recognized name) and of *hydrargyrum* (from ὕδωρ, water, and ἄργυρος, silver) in Græco-Latin.

's *Polytechn Journal*, 1862 , an improved form by is described in *Wiedemann s Annalen*, xii 425, 1881

This metal does not appear to have been known to the ancient Jews, nor is it mentioned by the earlier Greek writers Theophrastus (about 300 B C) mentions it as a derivative of cinnabar With the alchemists it was a substance of great consequence Being ignorant of its susceptibility of freezing into a compact solid, they did not recognize it as a true metal, and yet, on the authority of Geber, they held that mercury (meaning the predominating element in this metal) enters into the composition of all metals, and is the very cause of their metallicity When, about the beginning of the 16th century, chemistry and scientific medicine came to merge into one, this same mysterious element of ' mercury played a great part in the theories of pathology, and the metal, in the free as in certain combined states, came to be looked upon as a powerful medicinal agent, which position, on purely empirical grounds, it continues to hold to the present day

Mercury occurs in nature chiefly in the form of a red sulphide, HgS, called cinnabar, which, as a rule, is accompanied by more or less of the reguline metal,—the latter being probably derived from the former by some secondary reaction The most important mercury mines in Europe are those of Almaden in Spain and of Idria in Illyria, these until lately furnished the bulk of the mercury of commerce, but they are now almost eclipsed by the rich deposits of New Almaden in California Considerable quantities of mercury are said to be produced in China and in Japan, minor deposits are being worked in the Bavarian Palatinate, in Hungary, Transylvania, Bohemia, and Peru At Almaden the ore forms mighty veins traversing micaceous schists of the older transition period in Illyria it is disseminated in beds of bituminous schists or compact limestone of more recent date

Chemically speaking the extraction of mercury from its ores is a simple matter Metallic mercury is easily volatilized, and separated from the gangue, at temperatures far below redness, and cinnabar at a red heat is readily reduced to the metallic state by the action of iron or lime or atmospheric oxygen, the sulphur being eliminated in the first case as sulphide of iron, in the second as sulphide and sulphate of calcium, in the third as sulphurous acid gas To the chemical mind a close iron retort would suggest itself as the proper kind of apparatus for carrying out these operations but this idea is acted upon only in a few small establishments —for instance in that of Zweibrucken in the Palatinate, where lime is used as a decomposing agent In all the large works the decomposition of the cinnabar is effected by the direct exposure of the ore to the oxidizing flame of a furnace, and the mercury vapour, which of course gets diffused through an immense mass of combustion gases is sought to be recovered in more or less imperfect condensers

At Almaden this roasting distillation is effected in prismatic furnaces which by a second upper (brick) grating are divided into two flats the lower one serving for the generation of a wood fire while the upper accommodates the ore which is introduced through an opening in the dome shaped roof To avoid an excessive dilution of the mercury vapour with combustion gases part of these are led out laterally into a chimney and the rest allowed to strike up through the heap of ore The large mass of metalliferous vapour produced passes out through a system of pipes inserted laterally into the dome and so arranged that they follow first a descending and then an ascending plan to lead ultimately into a condensation chamber which communicates in its turn with a chimney The pipes are formed each of a large number of elongated pear shaped earthenware adapters (called *aludel*) which are telescoped into one another as in the case of the iodine distillation apparatus the joints being luted with clay The lowest row of aludels which lie in the line of intersection of the two inclined planes are pierced with holes below so that what arrives as liquid mercury there runs out into a gutter leading to a reservoir What of mercury vapour remains uncondensed in the aludels passes into the chamber the intention being to have it condensed there in reality a large proportion of the mercury passes out through the chimney (and through the numerous leaks in the aludels) into the atmosphere to poison the surrounding vegetation and the workmen Similar furnaces to the Almaden ones are used in Idria and at New Almaden, only the condensation apparatus are a little less imperfect But in all three places the loss of metal is very considerable, at New Almaden it is said to amount to close upon 40 per cent

The mercury obtained is purified mechanically by straining it through dense linen bags, and then sent out into commerce in leather bags, or in wrought iron bottles provided with screw plugs, each holding about 75 ℔ avoirdupois

According to Balling's *Metallurgische Chemie* (Bonn, 1882), the production of mercury in the years named was as follows —

Austria, exclusive of Hungary (1880)	369 tons
Hungary (1879)	180 ,,
Italy (1877)	55 ,,
Spain (1873)	929 ,,
United States (1875)	2054 ,,

Assuming the amount to be the same from year to year, this gives a total of 3587 tons

The price of the metal is subject to immense fluctuations, it generally ranges from 2s to 7s 6d a pound avoirdupois

Commercial mercury, as a rule, is very pure chemically, so that it needs only to be forced through chamois leather to become fit for all ordinary applications, but the metal, having the power of dissolving most ordinary other metals, is very liable to get contaminated with these in the laboratory or workshop, and requires then to be purified For this purpose a great many chemical methods have been proposed, which, however, all come to this, that the base admixtures are sought to be removed by treatment with nitric acid, oil of vitriol, or other agents which act preferably on the impurities The best of these methods is that of Bruhl, who shakes the metal with a solution of 5 grammes of bichromate of potash and a few cubic centimetres of sulphuric acid in one litre of water, until the red chromate of mercury, first produced, has disappeared, and its place been taken by green chromic sulphates The supernatant liquor and chromic scum are washed away by a powerful jet of water, and the clean metal is dried and filtered through a perforated paper filter The only really exhaustive method is redistillation out of a glass apparatus Unfortunately the operation is difficult of execution, as mercury "bumps badly on boiling, but this can be avoided by distilling the metal in a *perfect* vacuum An ingenious apparatus for this purpose in which the distilled metal itself is made to keep up the vacuum, was constructed lately by Leonhard Weber A U tube, the limbs of which are longer than the height of the barometer, is filled with pure mercury, and inverted, the one limb being made to dip into a vessel with pure the other into another containing the impure, mercury This second limb is inflated above so that the meniscus is about the middle of the bulb This bulb is heated and the consequence is that the metal there distils over into the first limb to add to the supply of pure metal, the impure rising up in the second by itself to maintain a constant level Dewar has modified the apparatus so that there is no need of a supply of pure metal to start with Absolutely pure mercury does not at all adhere to any surface which does not consist of a metal soluble in mercury Hence the least quantity of it, when placed on a sheet of paper, forms a neatly rounded off globule, which retains its form on being rolled about, and, when subdivided, breaks up into a number of equally perfect globules The presence in it of the minutest trace of lead or tin causes it to "draw tails A very impure metal may adhere even to glass, and in a glass vessel, instead of the normal convex, forms an irregular flat meniscus

Properties —The pure metal is silver white, and retains its strong lustre even on long exposure to ordinary air At – 38° 8 C, *i e*, – 37° 9 F (Balfour Stewart), it freezes, with considerable contraction, into a compact mass of regular octahedra, which can be cut with a knife and be flattened under the hammer. The specific gravity of the frozen metal is 14.39; that of the liquid metal at 0° C. is 13.595 (water of 4° C. = 1). Under 760 mm. pressure it boils at 357°.3 C. (675°.1 Fahr.) (Regnault). At very low temperatures it seems to be absolutely devoid of volatility (Faraday), but from −13° C. upwards (Regnault) it exhibits an appreciable vapour tension.

The following table gives the tensions "*p*," in millimetres of mercury of 0° C., for a series of centigrade temperatures "*t*," according to Regnault:—

t = 0°	10°	20°	50°	100°	150°	200°
p = .02	.03	.04	.11	.75	4.27	19.90

t = 250°	300°	350°	400°	450°	500°
p = 75.75	242.1	663.2	1588	3384	6520

According to the same authority, its average coefficient of expansion k per degree C. is as follows:—

	0–100° C.	0–200° C.	0–300° C.
k =	.0001815	.0001841	.0001866
or	1/5510	1/5432	1/5359

Its specific heat in the liquid state is .03332; that of the frozen metal (between −78° and −40° C.) is .0319 (Regnault). Its electric conductivity is $\frac{1}{67}$ of that of pure silver (Matthiessen). Its conductive power for heat is greater than that of water, and is proved (by Herwig) to be perfectly constant from 40° to 160° C. Its vapour density (air of the same temperature and pressure = 1) is 6.976 (Dumas), or 100.93 for hydrogen = 1. Hence its molecular weight ($H_2 = 2$) is 201.86. The atomic weight, by chemical methods, was found = 200.0 (Erdmann and Marchand); hence mercury vapour molecules consist of single atoms. Mercury does not appreciably absorb any chemically inert gas.

Mercury is in constant requisition in the laboratory. It is used for the collecting and measuring of gases, in the construction of thermometers, barometers, and manometers, for the determination of the capacity of vessels, and many other purposes. In medicine it serves for the preparation of mercurial ointment and of "hydrargyrum cum creta" (the chief component of "blue pills"), both are obtained by diligently triturating the metal with certain proportions of grease and chalk respectively until it is "deadened," *i.e.*, subdivided into invisibly small globules (see below).

Alloys.—Mercury readily unites directly with all metals (except iron and platinum) into what are called amalgams. In some cases the union takes place with considerable evolution of heat and large modification of the mean properties of the components. Thus, for instance, sodium when rubbed up with mercury unites with it with deflagration and formation of an alloy which, if it contains more than 2 per cent. of sodium, is hard and brittle, although sodium is as soft as wax and mercury a liquid. Liquid amalgams of gold and silver are employed for gilding and silvering objects of copper, bronze, or other base metal. The amalgam is spread out on the surface of the object by means of a brush, and the mercury then driven off by the application of heat, when a polishable, firmly adhering film of the noble metal remains. Copper amalgam containing from 25 to 33 per cent. of the solid metal, when worked in a mortar at 100° C., becomes highly plastic, but on standing in the cold for ten or twelve hours becomes hard and crystalline. Hence it is used for the stuffing of teeth. A certain amalgam of cadmium is similarly employed.

Oxides.—There are two oxides of mercury, namely an oxide Hg_2O called mercurous, and another, HgO, called mercuric oxide. The latter can be produced directly by keeping the metal for a long time in air at a temperature somewhat below its boiling point, when the oxide is gradually formed as a red powdery solid. This solid has long been known as "red precipitate," or as *mercurius præcipitatus per se*. Priestley made the important discovery that the "precipitate" when heated to dull redness is reduced to metal, with evolution of what has since been known as oxygen gas; but it was reserved for Lavoisier to correctly interpret this experiment and thus to establish our present views on the constitution of atmospheric air. The oxide is easily prepared by heating any nitrate of the metal as long as nitrous fumes are seen to go off (when it remains as a scaly mass, black when hot, red after cooling), or else by precipitating the solution of a mercuric salt with excess of caustic potash or soda, when it comes down as an amorphous yellow precipitate, which is free of combined water. Mercurous oxide, a black solid, can be obtained only indirectly, by the decomposition of mercurous salts with fixed caustic alkalies. Both oxides are insoluble in water, but dissolve in certain, and combine with all, aqueous acids with formation of mercury salts and elimination of water. Thus, for instance,

$$Hg_2O + 2HNO_3 = H_2O + \underset{\text{Mercurous nitrate}}{Hg_2(NO_3)_2}$$

$$HgO + 2HNO_3 = H_2O + \underset{\text{Mercuric nitrate}}{Hg(NO_3)_2}$$

The Nitrates.—When metallic mercury is set aside with its own weight of nitric acid of 1.2 specific gravity, at ordinary temperatures, the normal mercurous salt $Hg_2(NO_3)_2$ is gradually produced, and after a day or two is found to have separated out in colourless crystals. These are soluble (somewhat sparingly) in water acidulated with nitric acid, but are decomposed by the action of pure water with formation of difficultly soluble basic salt. When this salt (or the metal itself) is treated with excess of nitric acid it is oxidized into mercuric nitrate $Hg(NO_3)_2$, a white crystalline salt, readily soluble in water without decomposition.

The Sulphates.—Cold aqueous sulphuric acid does not act upon mercury, but the hot concentrated acid converts it first into mercurous and then into mercuric sulphate, with evolution of sulphurous acid:—

$$Hg_2 + 2H_2SO_4 = 2H_2O + SO_2 + Hg_2SO_4$$
$$Hg_2SO_4 + 2H_2SO_4 = 2H_2O + SO_2 + 2HgSO_4$$

Both salts form white crystalline magmas. The mercurous salt is difficultly soluble in water, and consequently producible by precipitation of the nitrate with sulphuric acid. The mercuric salt, when treated with water, is decomposed with formation of a yellow insoluble basic salt, which has long been known as *turpethum minerale*. Its composition is $SO_3.3HgO$ when produced by excess of hot water. Mercuric sulphate is of importance chiefly as forming the basis for the manufacture of the two chlorides.

The Chlorides.—These are both extensively used medicinal agents. The mercuric salt $HgCl_2$, known in medicine as "corrosive sublimate," is prepared by mixing the sulphate intimately with common salt and subjecting the mixture to sublimation, a little binoxide of manganese being added to oxidize the mercurous salt which is generally present as an impurity. The process is conducted in a glass flask buried in a hot sand bath. When the decomposition is accomplished, the sand is removed from the upper half of the flask and the temperature raised so that the chloride $HgCl_2$ produced sublimes up and condenses in the upper part as a "sublimate." The salt, as thus produced, forms compact crystalline crusts, which when heated, melt into a limpid liquid before volatilizing. It is soluble in water, 100 parts of which at 10°, 20°, 100° dissolve 6.57, 7.39, 54 parts of salt. Corrosive sublimate dissolves in 3 parts of alcohol and in 4 parts of ether. This salt, on account of its solubility in water, is a deadly poison. Mercurous chloride Hg_2Cl_2, better known as "calomel" (from *καλος* fair and *μελας* black, because it becomes dead black when treated with ammonia; mercuric chloride yielding a white product), is prepared by mixing corrosive sublimate with the proper proportion of metallic mercury ($HgCl_2 + Hg$) or mercuric sulphate with salt and mercury in the proportions of $HgSO_4 + Hg + 2NaCl$ and subjecting the mixture to sublimation in glass flasks. The salt Hg_2Cl_2 is thus obtained in the form of white opaque, crystalline crusts which when heated, volatilize, without previously melting, into a mixture of $HgCl_2$ and Hg vapour, which on cooling recombine into calomel. For medicinal purposes the sublimate is reduced to an impalpable powder, washed with water to remove any corrosive sublimate that may be present, and dried. Being insoluble in water it acts far less violently on the organism than mercuric chloride does. Its action, no doubt, is due to its very gradual conversion in the stomach into mercury and corrosive sublimate. Finely divided calomel can be produced, without trouble, by the precipitation of a solution of mercurous nitrate with hydrochloric acid or common salt; but this preparation is liable to be contaminated with mercurous nitrate, and even when pure has been found to act far more violently than ordinary calomel does. Hence its use is not tolerated by the pharmacopœias. According to Wohler a mercurous chloride, more nearly equivalent to the sublimed article, is producible by heating corrosive sublimate solution with sulphurous acid—

$$2HgCl_2 + H_2SO_3 + H_2O = H_2SO_4 + 2HCl + Hg_2Cl_2$$

The writer is unable to say whether Wohler's calomel has ever found its way anywhere into medicinal practice.

The Iodides.—The mercuric salt HgI_2 is produced in two ways, viz., first by mixing the two elementary components intimately and subjecting the mixture to sublimation, and secondly by precipitating corrosive sublimate solution with its exact equivalent of iodide of potassium. In the first case the salt is obtained in yellow crystals, which, on the slightest touch with a solid body, assume and then permanently retain a rich scarlet colour. The precipitation process at once yields the scarlet salt. The salt is insoluble in water, but soluble in alcohol and in iodide of potassium solution. The mercurous salt Hg_2I_2 is obtained by precipitating mercurous nitrate with iodide of potassium as a dirty green powder insoluble in water. Both iodides are used medicinally.

The Sulphides.—Mercurous sulphide, Hg_2S, does not seem to exist. The mercuric salt, HgS, exists in two modifications, of which one is amorphous and has a black colour, while the other is crystalline and red. The black one is obtained by precipitation of solutions of mercuric salts with excess of sulphuretted hydrogen or by direct synthesis. The right proportions of mercury and flowers of sulphur are rubbed together in a mortar until the whole is converted into a jet black uniform powder. This preparation (the *æthiops mineralis* of the pharmaceutist), however, is apt to be contaminated with uncombined sulphur and mercury. Application of a gentle heat causes exhaustive combination. The red sulphide, HgS, occurs in nature as cinnabar, and can be produced artificially from the black. The artificial preparation, known as vermilion, is highly valued as the most brilliant, stable, and innocuous of all mineral red pigments. Vermilion can be produced from the black sulphide in two ways, viz., first by sublimation, and secondly by treatment of it with fixed alkaline sulphide solution. According to Brunner, 100 parts of mercury are mixed intimately with 38 parts of flowers of sulphur, and the æthiops is digested, with constant agitation, in a solution of 25 parts of potash in 150 parts of water at 45° C. (the water lost by evaporation being constantly replaced) until the preparation has come up to its maximum of fire and brilliancy, which takes a good many hours. Purely sublimed vermilion has a comparatively dull colour, and must be manipulated with alkaline sulphide solution to give it the necessary fire. The action of the alkaline sulphide consists probably in this, that it dissolves successive instalments of the amorphous preparation and redeposits them in the crystalline form.

Mercuric Derivatives of Ammonia.—(1) Recently precipitated oxide HgO is digested, cold, in carbonic acid free ammonia, and the mixture allowed to stand for a few days. The liquor is then decanted off and the precipitate washed with alcohol and then with ether, and dried over sulphuric acid. The product is a yellow solid base ("Millon's base") of the composition

$$N_2H_6 + 4HgO + H_2O = N_2Hg_4O.2H_2O + 2H_2O$$

It is insoluble in alcohol and in ether and requires 13,000 parts of cold water for its solution. It readily unites with all acids forming salts, which, as a rule, are insoluble in water. Hence all ordinary salt solutions, when shaken with the base, are decomposed with elimination of the base of the salt. Thus, for instance, even such salts as alkaline nitrates, chlorides, or sulphates are decomposed with formation of solutions of caustic alkali.

(2) A body $N_2Hg_4I_2 + 2H_2O$, i.e., of the composition of the iodide corresponding to the oxide in (1), is produced as a brown precipitate when ammonia or an ammonia salt is added to a solution of mercuric iodide in iodide of potassium mixed with large excess of caustic potash or soda ("Nessler's reagent"). In very dilute solutions of ammonia Nessler's reagent produces only a brown or yellow coloration, which, however, is so intense that $\frac{1}{20000000}$th of ammonia in about 50 cubic centimetres of liquid becomes clearly visible.

(3) The chloride $NH_2Hg.Cl$ of the "ammonium" NH_2Hg is produced as an insoluble white precipitate when ammonia is added to a solution of corrosive sublimate. This substance is known in medicine as infusible white precipitate, in contradistinction to (4).

(4) The fusible white precipitate was at one time supposed to be identical with (3), and is obtained by boiling it with sal ammoniac solution. Its composition is $NH_2HgCl + NH_4Cl = N_2H_6Hg.Cl_2$.

Analysis.—Any ordinary solid mercury compound, when heated in a sublimation tube with carbonate of soda, yields a sublimate of metallic mercury, which, if necessary, needs only to be scraped together with a wooden spill to unite into visible globules. From any mercury salt solution the metal is precipitated by digestion with a piece of bright copper foil. The precipitated mercury forms a coating on the copper, which becomes silvery on being rubbed with blotting paper. When the quicksilvered copper is heated in a sublimation tube, it reassumes its red colour with formation of a sublimate of mercury.

Solutions of mercurous salts with hydrochloric acid give a white precipitate of calomel, which after filtration, is easily identified by its becoming jet black on treatment with ammonia. From mercuric solutions hydrochloric acid precipitates nothing, but stannous chloride, in its twofold capacity as a chloride and a reducing agent, yields a precipitate of calomel. On addition of an excess of reagent the precipitate becomes grey through conversion into finely divided quicksilver. Sulphuretted hydrogen, when added very gradually to an acid mercuric solution, gives at first an almost white precipitate, which, on addition of more and more reagent, assumes successively a yellow, orange, and at last jet black colour. The black precipitate is HgS, which is identified by its great heaviness, and by its being insoluble in boiling nitric and in boiling hydrochloric acid. A mixture of the two (aqua regia) dissolves it as chloride. (W. D.)

Therapeutics of Mercury

The use of mercury as a therapeutic agent is of comparatively recent date. To the Greeks and Romans its value was unknown, and the Arabian physicians only used it for skin affections. It was not till the middle of the 16th century that the special properties of mercury were fully appreciated, but since that time the metal has continued to hold a high though fluctuating value as a medicine. At first the metal in a finely divided state or in vapour was used, but very soon its various compounds were found to be endowed with powers even greater than those of the metal itself, and with the discovery of new compounds the number of mercurial medicines has largely increased.

The preparations now in use may be thus classified. (1) *Of the preparations containing metallic mercury* the chief members are blue pill (pilula hydrargyri), grey powder (hydrargyrum cum creta), and blue ointment (unguentum hydrargyri). The first consists of mercury, liquorice root, and confection of roses, the second of mercury and chalk, the third of mercury, suet, and lard. The power of the three preparations seems to depend on the fine state of subdivision of the mercury they contain, mercury in its ordinary liquid state seems devoid of medicinal properties. It is thought by some that the fine subdivision of the metal leads to the formation of a little oxide, and that the efficacy of the preparations in part depends on this. (2) Three oxides of mercury are employed in medicine,—the red, from which is made red precipitate ointment (unguentum hydrargyri oxydi rubri), the yellow, an allotropic form of the red, and the black oxide. The yellow and black oxides suspended in lime water form respectively yellow and black wash (lotio flava and lotio nigra). (3) The chlorides of mercury form a very important group: calomel (hydrargyri subchloridum) is a white heavy powder, corrosive sublimate (hydrargyri perchloridum) is a heavy crystalline substance. (4) Two iodides are used medicinally, they are known from their colour as the green and red iodides. (5) Nitrate of mercury enters into the composition of a powerful caustic known as the acid nitrate of mercury. It is also the active principle of citrine ointment (unguentum hydrargyri nitratis). (6) In this class only ammoniated mercury and its ointment commonly known as white precipitate ointment, are contained. Of the many compounds not included in the above classification the oleate and albuminate are the most important.

Mercurial preparations are largely employed as external applications. Several of them are potent agents for the destruction of the lower forms of animal life, and hence are employed to destroy parasites having their habitat in skin, hair, and clothing. The white and red precipitate ointments are specially effective in the destruction of pediculi, and blue ointment is occasionally used for the same purpose. Corrosive sublimate is, however, the most energetic of the mercurial parasiticides, and recent observations seem to show that it is superior to almost all other substances as a germ destroyer. It is sometimes used to get rid of ringworm. It should be remembered that corrosive sublimate is a powerful irritant to the skin, and also an active poison.

Acid nitrate of mercury is a caustic, and by it warts and small growths are sometimes removed, it is also one of the caustics occasionally applied to prevent the spread of lupus.

In skin diseases mercurial preparations are largely used, especially in some forms of eczema. A few grains of the red oxide or of ammoniated mercury in an ounce of zinc ointment are often found of great service in this ailment, citrine ointment is also useful.

Calomel ointment is not irritating, but rather tends to soothe. It is therefore sometimes applied to irritable rashes; in pruritus ani it is of special value. Mercurial preparations are not usually found of benefit in scaly eruptions. In acne a weak solution of corrosive sublimate is often most effective.

Preparations of mercury are often used to heal ulcers, especially those of syphilitic origin. Black wash is one of the commonest applications for this purpose. The red oxide ointment is at times employed to stimulate indolent ulcers, and it is capable of removing exuberant granulations (proud flesh), which sometimes retard the healing of wounds.

Mercury is largely used externally to promote the absorption of inflammatory products, especially in the neighbourhood of joints. The blue ointment is frequently employed for this purpose, more rarely a plaster containing mercury or a mercurial liniment. For effecting the absorption of goitre (Derbyshire neck) the ointment of the red iodide is often relied on, especially in India, where it is customary to expose the patient's neck to the sun after rubbing it with the ointment. In enlargements of the liver and spleen the application of mercurial ointment sometimes seems to promote reduction in size.

Taken internally in continued doses, mercury produces a peculiar effect known as salivation. First a metallic taste is experienced; this is followed by soreness of the gums, an undue flow of saliva, and fœtor of the breath. Further administration of the drug may increase greatly the salivary flow, and also lead to swelling of the tongue, ulceration of the mouth, and even disease of the jaw bone. At the same time the blood becomes impoverished, and feverishness with loss of flesh occurs. *A single large dose—rarely too a single* small dose—may produce some of the above symptoms. They may also follow the inhalation of the metal or its compounds, or their absorption through the skin. The long-continued inhalation of the vapour of mercury acts likewise on the nervous system, causing a peculiar kind of trembling. Mercurial tremor is sometimes seen in looking-glass makers, often in those who work in quicksilver mines.

Internally mercury is chiefly given for two purposes—(1) to check inflammation and cause the absorption of the products it gives rise to, and (2) to antagonize the syphilitic virus and remove the evils it causes. Some years ago the belief in the power of mercury to control inflammation was almost universal, and it was largely administered in almost all inflammatory affections; but of late it has been much less used, both because it seems doubtful whether it has really the power it was once supposed to have, and because of the possibility of evil results from its continued use. In peritonitis and iritis it is still often employed, small doses of calomel being given. Not unfrequently too it is administered in pericarditis and hepatitis, but in pneumonia, pleurisy, and most other inflammatory affections its use is now discarded by many physicians. As an antidote to the syphilitic poison it is still held in high esteem, though opinions vary much as to the extent of its power. There can be little doubt that, given in an early stage of the disorder, it minimizes the secondary symptoms, but it cannot be relied on to prevent their occurrence. It aids in removing the secondary symptoms, and tends to the avoidance of tertiary manifestations, which nevertheless sometimes occur even when mercury has been freely given. The custom of giving mercury till profuse salivation is established has long been abandoned; the aim now is so to give it as to prevent salivation occurring; for this purpose blue pill, calomel, and corrosive sublimate are given in very small doses, but if the gums become tender the dose is decreased or the administration stopped.

Mercurial treatment is sometimes carried out by rubbing the blue ointment into the skin, sometimes by exposing the patient to the fumes of calomel; syphilitic eruptions are often treated by such fumigation. More rarely mercury is introduced by injecting the albuminate or some other preparation under the skin or by means of suppositories. In children grey powder is generally used when mercurial treatment is required. Children bear mercury well.

Blue pill, calomel, and grey powder are often used as purgatives, and a power of promoting the secretion of bile is attributed to them. Experimentally it has not been proved that they stimulate the liver functions, but there is good reason for believing that they promote the expulsion of bile from the body. Grey powder is especially valued as a mild and efficient aperient for children, and is often given in the early stage of diarrhœa to expel the irritating contents of the bowel.

The use of calomel in tropical dysentery, once very prevalent, has within the last few years been abandoned. (D. J. L.)

MERGANSER, a word originating with Gesner (*Hist. Animalium*, iii. p. 129) in 1555, and for a long while used in English as the general name for a group of fish-eating Ducks possessing great diving powers, and forming the genus *Mergus* of Linnæus, now regarded by ornithologists as a Subfamily, *Merginæ*, of the Family *Anatidæ*. The Mergansers have a long, narrow bill, with a small but evident hook at the tip, and the edges of both mandibles beset by numerous horny denticulations, whence in English the name of "Saw-bill" is frequently applied to them. Otherwise their structure does not much depart from the Anatine or Fuliguline type. All the species bear a more or less developed crest or tuft on the head. Three of them, *Mergus merganser* or *castor*, *M. serrator*, and *M. albellus*, are found over the northern parts of the Old World, and of these the first two also inhabit North America, which has besides a fourth species, *M. cucullatus*, said to have occasionally visited Britain. *M. merganser*, commonly known as the Goosander, is the largest species, being nearly as big as the smaller Geese, and the adult male in breeding attire is a very beautiful bird, conspicuous with his dark glossy-green head, rich salmon-coloured breast, and the upper part of the body and wings black and white. This full plumage is not assumed till the second year, and in the meantime, as well as in the post-nuptial dress, the male much resembles the female, having, like her, a reddish-brown head, the upper parts greyish-brown, and the lower dull white. In this condition the bird is often known as the "Dun Diver." This species breeds abundantly in many parts of Scandinavia, Russia, Siberia, and North America, and of late years has been found to do so in Scotland, usually making its nest in the stump of a hollow tree or under a slab of rock. *M. serrator*, commonly called the Red-breasted Merganser, is a somewhat smaller bird; and, while the fully-dressed male wants the delicate hue of the lower parts, he has a gorget of rufous mottled with black, below which is a patch of white feathers, broadly edged with black. The male at other times and the female always much resemble the preceding. It is more numerous than the Goosander, with a somewhat more southern range, and is not so particular in selecting a sheltered site for its nest. Both these species have the bill and feet of a bright reddish-orange, while *M. albellus*, known as the Smew, has these parts of a lead colour, and the breeding plumage of the adult male is white, with quaint crescentic markings of black, and the flanks most beautifully vermiculated—the female and male in undress having a general resemblance to the other two already described—but the Smew is very much smaller in size, and, so far as is known, it invariably makes its nest in a hollow tree, as ascertained first by Wolley (*Ibis*, 1859, pp. 69 *et seq.*). This last habit is shared by *M. cucullatus*, the Hooded Merganser of North America, in size intermediate between *M. albellus* and *M. serrator*, the male of which is easily recognizable by his broad semicircular crest, bearing a fan-shaped patch of white, and his elongated subscapulars of white edged with black. The conformation of the trachea in the male of *M. merganser*, *M. serrator*, and *M. cucullatus* is very like that of the Ducks of the genus *Clangula*, but *M. albellus* has a less exaggerated development more resembling that of the ordinary *Fuligula*.[1] From the southern hemisphere two species of *Mergus* have been described, *M. octosetaceus* or *brasilianus*, Vieillot (*N. Dict. d'Hist. Naturelle*, ed. 2, xiv. p. 222; *Gal. des Oiseaux*, tom ii p 209, pl 283), inhabiting South America, of which but few specimens have been obtained, having some general resemblance to *M serrator*, but much more darkly coloured, and *M australis*, Hombron and Jacquemont (*Ann Sc Nat Zoologie*, ser 2, xvi p 320, *Voy au Pol Sud, Oiseaux*, pl 31, fig 2), as yet known only by the unique example in the Paris Museum procured by the French Antarctic expedition in the Auckland Islands This last species may perhaps be found to visit New Zealand, and should certainly be looked for there

---

[1] Hybrids between, as is presumed, *M. albellus* and *Clangula glaucion*, the common Golden-eye, have been described and figured (Eimbeck, *Isis*, 1831, p. 500, tab. iii.; Brehm, *Naturg. Vög. Deutschlands*, p. 930; Naumann, *Vög. Deutschl.*, xii. p. 194, frontispiece; Kjærbølling, *Journ. für Ornithologie*, 1853, Extraheft, p. 29; *Naumannia*, 1855, p. 327; *Ornith. Danica*, tab. lv. suppl. tab. 29) under the names of *Mergus anatarius*, *Clangula angustirostris*, and *Anas (Clangula) mergoides*, as though they were a distinct species; but the remarks of M. de Selys-Longchamps (*Bull. Ac. Bruxelles*, 1845, pt. ii. p. 354, and 1856, pt. ii. p. 21) leave little room for doubt as to their origin, which, when the cryptogamic habit and common range of their putative parents, the former unknown to the author last named, is considered, will seem to be still more likely.

Often associated with the Mergansers is the genus *Merganetta*, the so-called Torrent Ducks of South America, of which three species are said to exist, but they possess spiny tails and have their wings armed with a spur Whether they should be referred to the *Merginæ* or the *Erismaturinæ*—the Spiny tailed Ducks proper—is a question that further investigation must decide (A N)

MERGUI, a district of British Burmah, between 9 58 and 13 24 N lat It forms the southernmost district of the Tenasserim division, and is bounded on the N by Tavoy, E and S by Siam and W by the Bay of Bengal, with an area of 7810 square miles Two principal ranges cross Mergui from north to south, running almost parallel to each other for a considerable distance with the Tenasserim river winding between them till it turns south and flows through a narrow rocky gorge in the westernmost range to the sea Amongst these mountain ranges and their subsidiary spurs are several fertile plains, densely clothed with luxuriant vegetation Indeed, the whole district, from the water's edge to the loftiest mountain on the eastern boundary, may be regarded as almost unbroken forest, only 73 square miles being under cultivation The timber trees found towards the interior, and on the higher elevations, are of great size and beauty, the most valuable being teak, *thengan* (*Hopea odorata*) *kanyeng* (*Dipterocarpus tuberculatus*) &c The coast line of the district, studded with an archipelago of two hundred and seven islands, is much broken, and for several miles inland is very little raised above sea level, and is drained by numerous muddy tidal creeks Southwards of Mergui town it consists chiefly of low mangrove swamps alternating with small fertile rice plains After passing the mangrove limits, the ground to the east gradually rises till it becomes mountainous, even to the banks of the rivers, and finally culminates in the grand natural barrier dividing British Burmah from Assam The four principal rivers are the Tenasserim, Le gnya Pakchan and Palouk, the first three being navigable for a considerable distance of their course Coal is found in the district on the banks of the Tenasserim and its tributaries Gold copper, iron, and manganese are also found in various parts of the district

From the notices of early travellers it appears that Mergui when under Siamese rule before it passed to the Burmese was a rich and densely peopled country On its occupation by the British in 1824 25 it was found to be almost depopulated—the result of border warfare and of the cruelties exercised by the Burmese conquerors At that time the entire inhabitants only numbered 10 000 in 1876 they had increased to 51 846 (26 767 males and 25 079 females) Classified according to religion there were—Buddhists 48 750 Mohammedans 2555 Hindus 3[illegible] Christians and others 210 The district contains only one town (Mergui) with more than 5000 inhabitants Only 73 square miles of the district area were under cultivation in 1876 but this area is steadily though slowly increasing The principal manufactures are sugar boiling and tin smelting Mergui carries on a flourishing trade with Rangoon Bassein and the Straits Settlements The chief exports consist of rice rattans torches dried fish areca nuts sesamum seeds, molasses sea slugs edible birds nests and tin The staple imports are piece goods, tobacco cotton, earthenware tea and sugar The imperial revenue in 1876 amounted to £18 208 The climate is remarkably healthy, the heat due to its tropical situation being moderated by land and sea breezes The rainfall in 1876 amounted to 165½ inches The prevalent diseases are simple and remittent fevers, bronchitis, rheumatism, and small pox

MERGUI, chief town of the above district, is situated on an island at the mouth of the Tenasserim river The population (10,731 in 1876–77) consists of many races—Talaings, Burmese, Malays, Bengalis, Madrasis, Siamese, and Chinese Considerable trade is carried on with other Burmese ports and the Straits Settlements The harbour admits vessels drawing 18 feet of water

MÉRIDA, a city of 7390 inhabitants (1877), in the province of Badajoz, Spain, lies about 36 miles by rail eastward from Badajoz, on the Madrid and Badajoz line, on a small eminence on the right bank of the Guadiana It is connected by a branch line of rail with Llerena on the south-east The population is mostly agricultural The city owes its interest entirely to its Roman remains, which are numerous and extensive Of these one of the most important is the bridge of 81 arches of granite, erected by Trajan, it is 2575 feet long, 26 feet broad, and 33 feet above the bed of the river, it was unfortunately seriously injured during the siege of Badajoz in 1812 Of the colossal wall that formerly surrounded the town all that remains is a fine fragment, built of dressed stone, on the spot formerly occupied by the castellum, and where the provisor of the order of Santiago afterwards had his residence (El Conventual) In the town are some relics of temples of Diana, Mars, Fortuna, Jupiter, and others, and the Arco de Santiago, 44 feet high, also dates from Trajan's time, it has unfortunately been stripped of its marble casing Of the aqueduct from the laguna of Albuera thirty seven enormous piers are still standing, with ten arches in three tiers built of brick and granite To the east of the city is the circus, measuring some 1356 by 335 feet, the eight rows of seats still remain Further eastward is the almost perfect theatre, and near it are the remains of the amphitheatre, or, as some prefer to call it, naumachia (Baño de los Romanos)

Augusta Emerita was built in 25 B C by the emeriti of the fifth and tenth legions who had served in the Cantabrian war under Augustus It rose to great splendour and importance as the capital of Lusitania During the Gothic period it became an episcopal see and several provincial councils known to history were held there It was taken by Musa in 711, and reconquered by Alphonso in 1228

MERIDA, the capital of the Mexican state of Yucatan, stands in a great plain in the north of the peninsula, on a surface of limestone rock, about 25 miles from the port of Progreso on the Gulf of Mexico, with which it is connected by a railway opened in 1880 It is a well built city, with broad streets and squares, and the flat roofed stone houses, after the style introduced by the Spaniards, give a Moorish colour to the general view Besides the cathedral, an imposing edifice of the 16th century, the bishop's palace, and the Government house (all of which are situated in the principal square), the most notable building is the Franciscan monastery (1547–1600), which once harboured within its high and turreted walls no fewer than two thousand friars, but has been allowed to fall into complete decay since their expulsion in 1820 For a long time Merida has had the reputation of being one of the principal seats of culture in Mexico, and it possesses, besides the ecclesiastical seminary schools of law, medicine, and pharmacy, a literary institute, a public library, a theatre, and a considerable number of periodical publications Commercially it has shared in the prosperity which Yucatan in recent years owes to the development of the Sisal hemp trade, and its manufactures embrace cotton goods, cigars, sugar, and rum The population, estimated about 1840 as 25,000, was found in 1871 to number 33,025 The Mayas still form numerically the strongest element Previous to the Spanish conquest the site of Merida was occupied by the Maya town of Tehoo, which contained so great a number of artificial stone mounds that the new comers had abundant material for all their buildings The foundation of the city dates from 1542, and it was made a bishopric in 1561. Compare Stephen's *Yucatan*.

MERIDEN, a city of the United States, in New Haven county, Connecticut, 18 miles from New Haven by rail. It is a busy manufacturing town; the population has increased from 3559 in 1850 to 7426, 10,495, and 18,340 in 1860, 1870 and 1880. The Britannia Company alone employs upwards of 1000 hands, and sends out every year nearly $3,000,000 worth of Britannia metal and electro-plated goods; and tin ware, cutlery, brass work, flint glass, guns and woollen goods are also manufactured in the town. The State reform school had 307 inmates in 1880. A fortified tavern erected by Belcher in 1660 on the road between Boston and New Haven was the nucleus of Meriden; but the place was not incorporated as a town till 1866, and became a city in 1867.

MÉRIMÉE, Prosper (1803–1870), novelist, archæologist, essayist, and in all these capacities one of the greatest masters of French style during the century, was born at Paris on September 28, 1803, and died at Cannes on the 23d of the same month sixty-seven years later, having lived just long enough to know that ruin was threatening France. Not many details have been published in reference to his family, but his father seems to have been a man of position and competence. Mérimée had English blood in his veins on the mother's side, and was always considered, at least in France, to look and behave more like an Englishman than a Frenchman. He was educated for the bar, but entered the public service instead. A young man at the time of the romantic movement, he felt its influence strongly, though his peculiar temperament prevented him from joining any of the coteries of the period. This temperament was indeed exhibited by the very form and nature of the works in which he showed the influence of romanticism. Nothing was more prominent among the romantics than the fancy, as Mérimée himself puts it, for "local colour," the more unfamiliar the better. Mérimée exhibited this in an unusual way. In 1825 he published what purported to be the dramatic works of a Spanish lady, Clara Gazul, with a preface stating circumstantially how the supposed translator, one Joseph L'Estrange, had met the gifted poetess at Gibraltar. This was followed by a still more audacious and still more successful *supercherie*. In 1827 appeared a small book entitled *La Guzla* (the anagram of Gazul), and giving itself out as translated from the Illyrian of a certain Hyacinthe Maglanovich. This book, which has greater formal merit than *Clara Gazul*, is said to have taken in Sir John Bowring, a competent Slav scholar, the Russian poet Poushkin, and some German authorities, although not only had it no original, but, as Mérimée declares, a few words of Illyrian and a book or two of travels and topography were the author's only materials. In the next year appeared a short dramatic romance, *La Jacquerie*, in which all Mérimée's characteristics are visible—his extraordinary faculty of local and historical colour, his command of language, his grim irony, and a certain predilection for tragic and terrible subjects which was one of his numerous points of contact with the men of the Renaissance. This in its turn was followed by a still better piece, the *Chronique de Charles IX*, which stands towards the 16th century much as the *Jacquerie* does towards the Middle Ages. All these works were to a certain extent second-hand, being either directly imitated or prompted by a course of reading on a particular subject. But they exhibited all the future literary qualities of the author save the two chiefest, his wonderfully severe and almost classical style, and his equally classical solidity and statuesqueness of construction. For the latter there was not much opportunity in their subjects, and the former required a certain maturity and self-discipline which Mérimée had not yet given to himself. These were, however, displayed fully in the famous Corsican story of *Colomba*, published in the momentous year 1830. This, all things considered, is perhaps Mérimée's best tale.

He had already obtained a considerable position in the civil service, and after the revolution of July he was *chef de cabinet* to two different ministers. He was then appointed to the more congenial post of inspector of historical monuments. Mérimée was a born archæologist, combining linguistic faculty of a very unusual kind with the accurate scholarship which does not always accompany it, with remarkable historical appreciation and with a sincere love for the arts of design and construction, in the former of which he had some practical skill. In his official capacity he published numerous reports, some of which with other similar pieces have been republished in his works. He also devoted himself to history proper during the latter years of the July monarchy, and published numerous essays and works of no great length, chiefly on Spanish, Russian, and ancient Roman history. He did not, however, neglect novel writing during this period, and numerous short tales, almost without exception masterpieces, appeared chiefly in the *Revue de Paris*. He travelled a good deal, both for his own amusement and on official errands, and in one of his journeys to Spain, about the middle of Louis Philippe's reign, he made an acquaintance destined to influence his future life not a little—that of Madame de Montijo, mother of the future empress Eugénie. Mérimée, though in manner and language the most cynical of men, was a devoted friend, and shortly before the accession of Napoleon III he had occasion to show this. His friend Libri was accused of having stolen valuable manuscripts and books from French libraries, and Mérimée took his part so warmly that he was actually sentenced to and underwent fine and imprisonment. He had been elected of the Academy in 1844, and also of the Academy of Inscriptions, of which he was a prominent member. Between 1840 and 1850 he wrote more tales, the chief of which were *Arsène Guillot* and *Carmen*.

The empire made a considerable difference in Mérimée's life. He was not a very ardent politician, but all his sympathies were against democracy, and he had therefore no reason to object to the Bonapartist rule, especially as his habitual cynicism and his irreligious prejudices made legitimism distasteful to him. But the marriage of Napoleon III with the daughter of Madame de Montijo at once enlisted what was always the strongest of Mérimée's sympathies—the sympathy of personal friendship—on the emperor's side. He was made a senator, and continued to exercise his archæological functions, but his most important rôle was that of a constant and valued private friend of both the "master and mistress of the house," as he calls the emperor and empress in his letters. He was occasionally charged with a kind of irregular diplomacy, and once, in the matter of the emperor's *Cæsar*, he had to pay the penalty frequently exacted from great men of letters by their political or social superiors who are ambitious of literary reputation; but for the most part he was strictly the "ami de la maison." At the Tuileries, at Compiègne, at Biarritz, he was a constant, though not always a very willing guest, and his influence over the empress was very considerable and was fearlessly exerted, though he used to call himself, in imitation of Scarron, "le bouffon de sa majesté." His occupations during the last twenty years of his life were numerous and important, though rather nondescript. He found, however, time for not a few more tales, of which more will be said presently, and for two correspondences, which are not the least of his literary achievements, while they have an extraordinary interest of matter. One of these consists of the letters which have been published as *Lettres à une Inconnue*, the other of the letters addressed to Sir Antonio Panizzi, the late librarian of the British Museum. Various, though idle and rather impertinent, conjectures have been made as to the identity of the *inconnue* just mentioned. It is sufficient to say that the acquaintance extended over many years, that it partook at one time of the character of love, at another of that of simple friendship, and that Mérimée is exhibited under the most surprisingly diverse lights, most of them more or less amiable, and all interesting. The correspondence with Panizzi has somewhat less personal interest. Mérimée made the acquaintance originally by a suggestion that his correspondent should buy for the Museum some MSS. which were in the possession of Stendhal's sister, and for some years it was chiefly confined to correspondence. But Mérimée often visited England, where he had many friends (among whom the late Mr Ellice of Glengarry was the chief), and certain similarities of taste drew him closer to Panizzi personally, while during part of the empire the two served as the channel for a kind of unofficial diplomacy between the emperor and certain English statesmen. These letters are full of shrewd *aperçus* on the state of Europe at different times. Both series abound in gossip, in amusing anecdotes, in sharp literary criticism, while both contain evidences of a cynical and Rabelaisian or Swiftian humour which was very strong in Mérimée. This characteristic is said to be so prominent in a correspondence with another friend, which now lies in the library at Avignon, that there is but little chance of its ever being printed. A fourth collection of letters, of much inferior extent and interest, has been printed by M. Blaze de Bury under the title of *Lettres à une autre Inconnue*. In the latter years of his life Mérimée suffered very much from ill health. It was necessary for him to pass all his winters at Cannes, where his constant companions were two aged English ladies, friends of his mother. The terrible year found him completely broken in health, and anticipating the worst for France. He lived long enough to see his fears realized, and to express his grief in some last letters, and he died on September 23, 1870.

Mérimée's character (which has been unwarrantably slandered by those to whom political difference or his sarcastic intolerance of pretension in literature made him obnoxious) was a peculiar and in some respects an unfortunate one, but by no means unintelligible, and perhaps in a minor degree not uncommon. Partly by temperament, partly, it is said, owing to some childish experience, when he discovered that he had been duped and determined never to be so again, partly owing to the example of Beyle, who was a friend of his family and of whom he saw much, Mérimée appears at a comparatively early age to have imposed upon himself as a duty the maintenance of an attitude of sceptical indifference and sarcastic criticism. He certainly succeeded. Although, as has been said, a man of singularly warm and affectionate feelings, he obtained the credit of being a cold-hearted cynic, and, though he was both independent and disinterested, he was declared to be a hanger-on and toad-eater of the imperial court. These imputations were wholly undeserved, and indeed were prompted to a great extent by the resentment felt by his literary equals on the other side at the cool ridicule with which he met them. But he deserved in some of the bad as well as many of the good senses of the term the phrase which we have applied to him of a man of the Renaissance. He had the warm partisanship and amiability towards friends and the scorpion-like sting for his foes, he had the ardent delight in learning, and especially in matters of art and belles lettres, which had the scepticism, the voluptuousness, the curious delight in the contemplation of the horrible, which marked the men of letters of the humanist period. Like them he was a man of the world, and a man who without any baseness liked a king's palace better than a philosopher's hovel. Like them he had an acute judgment in matters of business, and like them a singular consciousness of the nothingness of things. Even his literary work has this Renaissance character. It is tolerably extensive, amounting to some seventeen or eighteen volumes, but its bulk is not great for a life which was not short and which was occupied at least nominally in little else. About a third of it consists of the letters already mentioned, which will always be to those who delight in personal literature the most attractive part, and which, though in a fragmentary fashion, are really important as throwing side lights on history. Rather more than another third consists of the official work which has been already alluded to—reports, essays, short historical sketches, the chief of which latter is a history of Pedro the Cruel, and another of the curious pretender known in Russian story as the false Demetrius. Some of the literary essays, such as those on Beyle, on Turguenief, &c., where a personal element enters, are excellent. Against others and against the larger historical sketches—admirable as they are—M. Taine's criticism that they want life has some force. They are, however, all marked by Mérimée's admirable style, by his sound and accurate scholarship, his strong intellectual grasp of whatever he handled, his cool unprejudiced views, his marvellous faculty of designing and proportioning the treatment of his work. It is however, in the remaining third of his work, consisting entirely of tales either in narrative or in dramatic form, and especially in the former, that his full power is perceived. He translated a certain number of things (chiefly from the Russian), but his fame does not rest on these, on his already mentioned youthful supercheries, or on his later semi-dramatic works. There remain about a score of tales extending in point of composition over exactly forty years, and in length from that of *Colomba*, the longest, which fills about one hundred and fifty pages, to that of *L'Enlèvement de la Redoute*, which fills just half a dozen. They are unquestionably the best things of their kind written during the century, the only *nouvelles* that can challenge comparison with them being the very best of Gautier, and one or two of Balzac. The motives are sufficiently different. In *Colomba* and *Mateo Falcone*, the Corsican point of honour is drawn on; in *Carmen* (written apparently after reading Borrow's Spanish books), the gipsy character; in *La Vénus d'Ille* and *Lokis* (two of the finest of all) certain grisly superstitions, in the former case that known in a milder form as the ring given to Venus, in the latter a variety of the were-wolf fancy. *Arsène Guillot* is a singular satire full of sarcastic pathos on popular morality and religion; *La Chambre Bleue*, an 18th century *conte* worthy of Crébillon for grace and wit and superior to him in delicacy. *The Capture of the Redoubt* just mentioned is a perfect piece of description. *L'Abbé Aubain* is again satirical. *La Double Méprise* (the authorship of which was objected to Mérimée when he was elected of the Academy) is an exercise in analysis strongly impregnated with the spirit of Stendhal, but better written than anything of that writer's. These stories, with his letters, assure Mérimée's place in literature at the very head of the French prose writers of the century. He had undertaken an edition of Brantôme for the Bibliothèque Elzévirienne, but it was never completed.

Mérimée's works have only been gradually published since his death. The latest, *The Letters to Panizzi*, which have also appeared in English, bears date 1881. There is as yet no uniform or handsome edition, but almost everything is obtainable in the collections of MM. Charpentier and Calmann Lévy. (G. SA.)

MERINO. See SHEEP and WOOL.

MERIONETH (Welsh *Meirionydd*), a maritime county of North Wales, is bounded N. by Carnarvon and Denbigh, S.E. by Denbigh and Montgomery, and W. by Cardigan Bay. It is triangular in shape, its greatest length north-east to south-west being 45 miles, and its greatest breadth north-west to south-east about 30 miles. The area is 385,291 acres, or about 600 square miles. Next to Carnarvon, Merioneth is the most mountainous county in Wales. If the scenery is less bold and striking than that of Carnarvon, it excels it in richness, variety, and picturesque beauty. Its lofty mountains are interpenetrated by dark deep dells or smiling vales. The outlines of its rugged crags are softened and adorned by rich foliage. The sea views are frequently fine, and rivers, lakes, and waterfalls add a romantic charm to the valleys. The highest summits in the county are the picturesque Cader Idris (which divides into three peaks,—one, Pen y Gadair, having an altitude of 2914 feet), Aran Fawddwy (2955), Arenig fawr (2818), Moelwyn (2566), Rhobell fawr (2360). The finest valleys are those of Dyfi, Dysynni, Talyllyn, Mawddach, and Festiniog. The river Dyfrdwy or Dee rises 10 miles north-west of Bala, and, after passing through Bala Lake, flows north-east by Corwen to Denbighshire. The Dyfi rises in a small lake near Aran Fawddwy, and expands into an estuary of Cardigan Bay. The Mawddach or Maw, from the north of Aran Fawddwy, has a course of 12 miles south-west, during which it is joined by several other streams. The Dwyryd and other streams unite in forming the estuary of Traeth Bach. The finest waterfalls are the

Rhaiadr y Glyn near Corwen, Rhaiadr Du, and Pistyll Cain, the latter 150 feet high. The lakes are very numerous, but small, the largest being Bala Lake, or Pimblemere (in Welsh, Llyn Tegid, fair lake), 4 miles long by 1 broad, and Llyn Mwyngil (lake in a sweet nook) in the vale of Talyllyn. Both are much frequented by anglers. On account of frequent indentations the coast line is about 100 miles long. Sandy beaches intervene between the rocky shores. Frequent shoals and sandbanks render navigation very dangerous. There are only two harbours of importance, Barmouth and Aberdovey.

A mountain tract of the county 15 miles from north to south by 10 from east to west, stretching from the coast inland, is of the Cambrian age, composed of grits, quartzose, and slates, and comprising the Merionethshire anticlinal. This tract is enclosed on the north, east, and south by the Menevian, Lingula, Tremadoc, and Arenig beds, which are pierced by numerous dykes and intrusive masses, mostly greenstone. Rhobell fawr is one of the greatest igneous masses in the whole area of the Lingula beds. The Arenig beds are interstratified with and overlaid by accumulations of volcanic ashes, felspathic traps, or lava flows, which form the rugged heights of Cader Idris, the Arans, the Arenigs, Manod, and Moelwyn, and these are in turn overlaid by the Llandeilo and Bala beds, the latter including the Bala limestone. Extensive slate quarries are worked near Festiniog, mostly underground, in strata of the Llandeilo age, giving employment to about 4000 men. Gold, lead, copper, and manganese have been obtained in various places.

Climate and Agriculture.—The climate varies much with the elevation, in some places being bleak and cold, and in others remarkably equable and genial. At Aberdovey it is proverbially mild, and the myrtle grows in the open air. All attempts to introduce fruit have proved abortive in most parts of the county. The soil is generally thin and poor, with fertile tracts in the valleys. A great portion of the moss has been reclaimed within late years.

According to the agricultural returns for 1882, there were 154 406 acres, or considerably less than half the total area, under cultivation. Of this as much as 119,133 acres were permanent pasture, and 13,755 under rotation grasses. Of the 17,312 acres under corn crops, 11,232 were under oats and 4807 under barley. Potatoes occupied 2392 acres, and turnips only 1496 acres. The area under woods extended to 15,049 acres.

The total number of horses in 1882 was 6088. A breed of ponies is peculiar to this county and Montgomeryshire. The rearing of horned cattle and dairy farming are largely carried on, but the number of cattle (37,643) is considerably under the average of Wales generally. On the other hand the number of sheep in 1882 was 400 553, a larger number than in any other county of Wales, and much beyond the general average in the principality. They are a small hardy breed, which grow heavy fleeces. Goats frequent the loftier crags.

According to the latest return the number of proprietors was 1695, possessing 303 374 acres, with a gross annual value of £183,253. Of the owners 1044, or 62 per cent., possessed less than 1 acre, the average extent of the properties being 189 acres, and the average value per acre a little over 12s. There were ten proprietors who possessed over 5000 acres, viz., Sir W. W. Wynn, 20,295; E. J. L. Price, 17 718; T. P. Lloyd, 16,975; Mrs Kirkby, 13 410; Hon. C. H. Wynn, 10 504; A. J. G. Corbet, 9347; Sir L. Buckley, 8738; W. E. Oakeley, 6018; W. O. Gore, 5497; and R. M. Rickards, 5701.

Manufactures.—Woollen goods are manufactured in various places, especially at Dolgelly. They are principally coarse druggets, kerseymeres, and flannels. The knitting of stockings was a great industry at the close of last century, the value of the sales at Bala being estimated at from £17,000 to £19,000 annually.

Railways.—The Cambrian Railway skirts the coast from Portmadoc to Aberdovey. At Barmouth Junction a branch of the same crosses to Dolgelly, where it is joined by a branch of the Great Western Railway. Another branch of the Great Western unites Bala and Festiniog, and the latter place has railway connexion both with Llandudno Junction and with Portmadoc.

Administration and Population.—Merionethshire comprises five hundreds and thirty three civil parishes. It has one court of quarter sessions, and the number of petty sessional divisions is six. Ecclesiastically it is partly in the diocese of Bangor, partly in that of St Asaph. The county returns one member to parliament. There is no municipal or parliamentary borough. The towns returned in 1881 as urban sanitary districts are Bala (1653), Barmouth (1512), Dolgelly (2457), Festiniog (11,272), and Towyn (3363). Since 1801 the population has nearly doubled. From 29,506 in that year it had increased in 1851 to 38,963, in 1871 to 46 598, and in 1881 to 54,793, of whom 27,576 were males, and 27,217 females.

History and Antiquities.—Originally Merioneth belonged to the territory of the Ordovices, and under the Romans it was included in *Britannia Secunda*. There are many Celtic, Roman, and mediæval remains. Caer Drewyn on the Dee, near Corwen, was a British camp. There are numerous cromlechs in various parts of the county, especially near the sea coast. The *Via Occidentalis* of the Romans passed through Merioneth from south to north, and at Tomen-y Mur was joined by a branch of the South Watling Street, the Castell Tomen y Mur being supposed to be identical with the Roman station of Heriri Mons. The immense ruin of Castel y-Bere was originally one of the largest castles in Wales, but has not been occupied since the time of Edward I. During the Wars of the Roses the castle of Harlech, still a fine ruin, was held by the Lancastrians, and was the last in Wales to surrender. Of ecclesiastical remains the most important is Cymmer Abbey, founded by the Cistercians in 1198, a very fine ruin containing architecture of various periods from Norman to Perpendicular. There are numerous interesting old churches.

MERLIN. See FALCON.

MERMAIDS AND MERMEN, in the popular mythology of England and Scotland, are a class of beings more or less completely akin to man, who have their dwelling in the sea, but are capable of living on land and of entering into social relations with men and women.[1] They are easily identified, at least in some of their most important aspects, with the Old German Meriminni or Meerfrau, the Icelandic Hafgufa, Margygr, and Marmennill (mod. Marbendill), the Danish Hafmand or Maremind, the Irish Merrow or Merruach, the Marie Morgan of Brittany and the Morforwyn of Wales,[2] and they have various points of resemblance to the vodyany or water sprite and the rusalka or stream fairy of Russian mythology. The typical mermaid (who is much more frequently described than the merman) has the head and body of a woman, usually of exceeding loveliness, but below the waist is fashioned like a fish with scales and fins. Her hair is long and beautiful, and she is often represented, like the Russian rusalka, as combing it with one hand while in the other she holds a looking glass. At other times, like the rusalka, she is seen engaged in the more prosaic occupation of washing or beating clothes; but this, as, for example, in Hugh Miller's terrible Loch Slin legend, is a sign of some impending calamity. For a time at least a mermaid may become to all appearance an ordinary human being, and from a very striking Irish legend ("The Overflowing of Lough Neagh and Liban the Mermaid," in Joyce's *Old Celtic Romances*) it is evident that a human being may also for a time be transformed into a mermaid.

The mermaid legends, both English and other, may be grouped as follows. A. *A mermaid or mermen either voluntarily or under compulsion reveal things that are about to happen.* Thus the two mermaids (merewîp) Hadeburc and Sigelint, in the *Nibelungenlied*, disclose his future course to the hero Hagen, who, having got possession of their garments, which they had left on the shore, compels them to pay ransom in this way. According to Resenius, a mermaid appeared to a peasant of Samsoe, foretold the birth of a prince, and moralized on the evils of intem perance, &c (*Kong Frederichs den andens Kronike*, Copenhagen, 1680, p 302) B *A Mermaid imparts supernatural powers to a human being* Thus in the beautiful story of "The Old Man of Cury" (in Hunt's *Popular Romances of the West of England*, 1871) the old man, instead of silver and gold, obtains the power of doing good to his neighbours by breaking the spells of witchcraft, chasing away diseases, and discovering thieves John Reid, the Cromarty shipmaster, was more selfish,—his "wishes three" being that neither he nor any of his friends should perish by the sea, that he should be uninterruptedly successful in everything he undertook, and that the lady who scorned his love should scorn it no more C *A mermaid has some one under her protection, and for wrong done to her ward exacts a terrible penalty* One of the best and most detailed examples of this class is the story of the "Mermaid s Vengeance ' in Mr Hunt's book already quoted D *A mermaid falls in love with a human being, lives with him as his lawful wife for a time, and then, some compact being unwittingly or intentionally broken by him, departs to her true home in the sea* Here, if its mermaid form be accepted, the typical legend is undoubtedly that of *Melusina*, which, being made the subject of a full fledged romance by Jean d Arras, became one of the most popular folk books of Europe, appearing in Spanish, German, Dutch, and Bohemian versions Melusina, whose name may be a far off echo of the Mylitta (Venus) of the Phœnicians, was married to Raymond of Lusignan, and was long afterwards proudly recognized as one of their ancestors by the Luxembourg, Rohan, and Sassenaye families, and even by the emperor Henry VII Her story will be found in Baring Gould s *Myths of the Middle Ages* E *A mermaid falls in love with a man, and entices him to go and live with her below the sea, or a merman wins the affection or captures the person of an earthborn maiden* This form of legend is very common, and has naturally been a favourite with poets Macphail of Colonsay successfully rejects the allurements of the mermaid of Corrievrekin, and comes back after long years of trial to the maid of Colonsay[1] The Danish ballads are especially full of the theme, as "Agnete and the Merman," an antecedent of Matthew Arnold's "Forsaken Merman' , the "Deceitful Merman, or Marstig's Daughter", and the finely detailed story of Rosmer Hafmand (No 49 in Grimm)

---

[1] The name *mermaid* is compounded of the A.-S. *mere*, a lake, and *magd*, a maid; but, though *mere-wif* occurs in Beowulf, *mermaid* does not appear till the Middle English period (Chaucer, *Romaunt of the Rose*, &c.). In Cornwall the fishermen say *merry-maids* and *merry-men*. The connexion with the sea rather than with inland waters appears to be of later origin. 'The Mermaid of Martin Meer' (Roby's *Traditions of Lancashire*, vol. ii.) is an example of the older force of the word; and such mere-women are known to the country folk in various parts of England (*e.g.* at Newport in Shropshire, where the town is some day to be drowned by the woman's agency).

[2] See Rhys, "Welsh Fairy Tales," in *Y Cymmrodor*, 1881-1882.

In relation to man the mermaid is usually of evil issue if not of evil intent She has generally to be bribed or compelled to utter her prophecy or bestow her gifts, and whether as wife or paramour she brings disaster in her train In itself her sea life is often represented as one of endless delights, but at other times a mournful mystery and sadness broods over it The fish tail, which in popular fancy forms the characteristic feature of the mermaid, is really of secondary importance, for the true Teutonic mermaid—probably a remnant of the great cult of the Vanir—had no fish tail,[2] and this symbolic appendage occurs in such remote mythological regions as to give no clue to historical connexion The Tritons, and, in the later representations, the Sirens of classical antiquity, the Phœnician Dagon, and the Chaldæan Oannes are all well known examples, the Ottawas and other American Indians have their man fish and woman fish (Jones, *Traditions of the North American Indians*, 1830), and the Chinese tell stories not unlike our own about the sea-women of their southern seas (Dennis, *Folklore of China*, 1875)

Quasi historical instances of the appearance or capture of mermaids are common enough,[3] and serve, with the frequent use of the figure on signboards and coats of arms, to show how thoroughly the myth had taken hold of the popular imagination[4] A mermaid captured at Bangor, on the shore of Belfast Lough, in the 6th century, was not only baptized, but admitted into some of the old calendars as a saint under the name of Murgen (*Notes and Queries*, Oct 21, 1882), and Stowe (*Annales*, under date 1187) relates how a man fish was kept for six months and more in the castle of Orforde in Suffolk As showing how legendary material may gather round a simple fact, the oft-told story of the sea woman of Edam is particularly interesting The oldest authority, Joh Gerbrandus a Leydis, a Carmelite monk (*ob* 1504), tells (*Annales*, &c, Frankfort, 1620) how in 1403 a wild woman came through a breach in the dike into Purmerlake, and, being found by some Edam milkmaids, was ultimately taken to Haarlem and lived there many years Nobody could understand her, but she learned to spin, and was wont to adore the cross Ocka Scharlensis (*Chronyk van Friesland*, Leeuw, 1597) reasons that she was not a fish because she could spin, and she was not a woman because she could live in the sea, and thus in due course she got fairly established as a genuine mermaid Vosmaer, who has carefully investigated the matter, enumerates forty writers who have repeated the story, and shows that the older ones speak only of a woman (see "Beschr van de zoogen Meermin der stad Haarlem," in *Verh van de Holl Maatsch van K en Wet*, part 23, No 1786) As for the stuffed mermaids which have figured from the days of Bartholomew Fair downwards, it is enough to mention that exhibited in the Turf Coffee house, London, in 1822, and carefully drawn by Cruikshank (compare Chambers, *Book of Days*)

The best account of the mermaid myth is in Baring Gould's *Myths of the Middle Ages* See also, besides works already mentioned, Pontoppidan, who in his logically credulous way collects much matter to prove the existence of mermaids, Maillet, *Telliamed*, Hague, 1755, Grimm, *Deutsche Mythologie* i 404, and *Altdan Heldenlieder*, 1811, Waldron's *Description* and Train's *Hist and Stat Acc of the Isle of Man* Folklore Society's *Record*, vol ii, Napier *Hist and Trad Tales connected with the South of Scotland*, Sebillot, *Traditions de la Haute Bretagne*, 1882, and *Contes des Marins*, 1882 (H A W)

MEROE, in classical geography (Strabo, xvii 2, 2, Pliny, ii 73, v 10, Ptol, p 201), was the metropolis of Æthiopia, situated on an island of the same name between the Nile and the Astaboras (Atbara) The "island" is only an inaccurate name for the fertile plain between the two rivers This Meroe, first mentioned by Herodotus (ii 29 sq), succeeded an older Ethiopian kingdom of Napata lower down the Nile, originally subject to and civilized from Egypt, but which afterwards became independent and even sent forth an Ethiopian dynasty to reign in Egypt, to which the So and Tirhaka of the Bible belonged (see ETHIOPIA) The name of Meroe in the form Merawi is now given to Napata The later Meroe retained its independence when Egypt fell under foreign sovereigns Diodorus (iii 6) describes it as entirely controlled by the priesthood till a native prince Ergamenes destroyed the sacerdotal caste in the time of Ptolemy II Queen Candace (Acts viii 27) was probably sovereign of Meroe, see Lepsius's *Letters*, Eng tr, pp 196, 206, and comp Strabo, xvii 1, 54 for a Queen Candace in Augustus's time when the Romans under Petronius advanced to Napata Meroe was visited by Greek merchants, and the astronomical expedition of Eratosthenes determined its latitude with great accuracy An exploring party in the reign of Nero found that the country below Meroe, formerly the site of many towns, had become almost wholly waste (Pliny, vi 29) From the 6th to the 14th century of our era the Christian (Jacobite) realm of Dongola occupied the place of the older kingdom The ruins of Meroe and Napata were fully explored by Lepsius in 1844, and the monuments are pictured in his *Denkmaler*

---

[1] See Leyden s "The Mermaid,' in Sir Walter Scott s *Border Minstrelsy*

[2] Karl Blind, "New Finds in Shetlandic and Welsh Folk Lore," in *Gentleman s Magazine*, 1882

[3] Compare the strange account of the quasi human creatures found in the Nile given by Theophylactus, *Historiæ*, viii 16, pp 299-302 of Bekker's ed

[4] See the paper in *Jour Brit Arch Ass*, xxxviii, 1882, by H S Cuming, who points out that mermaids or mermen occur in the arms of Earls Caledon, Howth, and Sandwich, Viscounts Boyne and Hood, Lord Lyttleton, and Scott of Abbotsford, as well as in those of the Ellis, Byron, Phene, Skeffington, and other families The English heralds represent the creatures with a single tail, the French and German heralds frequently with a double one

MERSEBURG, the chief town of a district of the same name in the Prussian province of Saxony, is situated on the river Saale, 10 miles to the south of Halle and 17 to the west of Leipsic It consists of a quaint and irregularly built old town, with two extensive suburbs, and contains six churches and several schools and charitable institutions The cathedral is an interesting old pile, with a Romanesque choir of the 11th, a transept of the 13th, and a Late Gothic nave of the 16th century Among its numerous monuments is that of Rudolph of Swabia, who fell in 1080 in an encounter with his rival Henry IV It contains two paintings by Lucas Cranach Contiguous to the cathedral is the Gothic chateau, formerly the residence of the Saxon princes and the bishops of Merseburg The town house, the post office, and the "standehaus" for the meetings of the provincial estates are also noteworthy buildings The industries of Merseburg consist of the manufacture of cardboard and coloured paper, dyeing, glue boiling, machine making, calico printing, tanning, and brewing Its population in 1880 was 15,205

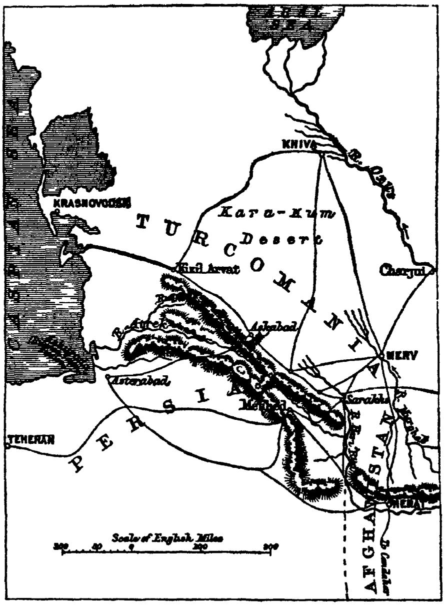
Merseburg (*i e* march town) is one of the oldest towns in Germany From the 9th century down to 1007 it was the capital of a countship of its own name and from 968 to 1543 it was the seat of a bishop In the 10th 11th, and 12th centuries it was a favourite residence of the German emperors and at this time its fairs enjoyed the importance afterwards inherited by those of Leipsic The town was repeatedly visited by destructive conflagrations in the 14th to 17th centuries and also suffered severely during the Thirty Years War From 1656 to 1738 it was the residence of the dukes of Saxe Merseburg The great victory gained by the emperor Henry I over the Huns in 933 is believed to have been fought on the Keuschberg near Merseburg

MERTHYR TYDFIL, or **MERTHYR TYDVIL**, a parliamentary borough and market-town of Glamorganshire, South Wales, is situated in a bleak and hilly region on the river Taff, and on several railway lines, 25 miles north north west of Cardiff and 30 east north east of Swansea The town, which consists principally of the houses of workmen is for the most part meanly and irregularly built, and at one time, on account of its defective sanitary arrangements, was frequently subject to epidemics of great severity Within recent years great improvements have taken place, and the town now possesses both a plentiful supply of pure water and an excellent system of sewage There are also some good streets with handsome shops, while in the suburbs there are a number of private residences and villas inhabited by the wealthier classes Apart from its extensive iron and steel works, the town possesses no feature of interest It is situated in the centre of the South Wales coal basin, and the rich coal mines in the vicinity supply great facilities for the iron industries At Merthyr Tydfil, which is said to have received its name from the martyrdom of a British saint Tydfil, there were smelting works at a very early period, but none of any importance until 1755 From about forty years ago until 1875 the manufacture of bar iron developed with great rapidity, but since then the production of steel has largely taken its place The borough returns two members to parliament The population of the urban sanitary district in 1871 was 51 949 and in 1881 it was 48,857, the population of the parliamentary borough, which includes the parish of Aberdare and parts of the parishes of Llanwonno and Merthyr Tydfil and of Vainor (Brecon), and has an area of 29,954 acres, was in the same years 97,020 and 91,347

MERV, **MERU**, or **MAOUR**,[1] a district of Central Asia, situated on the border land of Iran and Turan

The oasis of Merv lies in the midst of a desert, in about 37° 30 N lat and 62° E long It is about 250 miles from Herat, 170 from Charjui on the Oxus, 360 from Khiva, and 175 from Gawars, the nearest point in the newly acquired (1881) Russian territory of Akhal

The great chain of mountains which, under the name of Paropamisus and Hindu Kush, extends across the Asiatic continent from the Caspian to China, and forms the line of ethnic demarcation between the Turanian and Indo-Germanic races, is interrupted at a single point, that point is on the same longitude with Merv Through or near the trouee or gap which nature has created flow northward in parallel courses the rivers Heri rud (Tejend) and Murghab, until they lose themselves in the desert of Kara kum—that large expanse of waste, known also as Turcomania, which spreads at the northern foot of the mountains, and stretches from the lower Oxus to the Caspian



Neighbourhood of Merv

Whether as a satrapy of Darius and subsequently as a province of Alexander, whether as the home of the Parthian race, whether as a bulwark against the destructive waves of Mongol invasion, or later as the glacis of Persian Khorasan, the valleys of those rivers—the district of Merv

---

[1] Merv is the modern Persian name The river *Margus*, now the Murghab, on which was built the ancient city, is derived from *Margu*, the name of the province as recorded in the Behistan inscriptions of Darius. Spiegel connects the name *Margu* with old Bactrian *meregho*, bird, in allusion to the numerous swarms of birds that gather there So, too, the river name Murghab means bird water The district appears to have been known in the 5th century as Marv i rud, so that the river was then the Marv The name *Merum* for the district occurs in the Armenian geography ascribed to Moses of Khorene, written probably in the 7th century (ed Patkanoff) Maour is the Uzbek name, and of comparatively recent date

—have ever been important outposts on the borders of Iran In bye gone epochs their banks have, under powerful rulers, been studded with populous and flourishing cities, which bore the name of "Sovereign of the Universe (*Merv Shah i-jehan*), and vied for fame with "Balkh, the Mother of cities', of late times, with weakness or absence of government, those same banks have become choked with fallen battlements and ruins, the home of the snake and the jackal

Merv has soared to prosperity or fallen to decay according to her political status at the moment, and history, which repeats itself, may yet have to sing her praises in the future as it has done in the past All that human life in the desert requires is there,—water in abundance, and a soil unsurpassed for fertility Good government is alone wanting to turn those natural gifts to full account

The present inhabitants of the district are Turcomans of the Tekke tribe, who, like the other tribes inhabiting Turcomania, enjoyed until the approach of the Russians virtual independence, and acknowledged allegiance to no one,—a pastoral people who eked out a miserable existence by the trade of passing caravans, and in bad times pillaged the neighbouring and equally barbarous states, to whose reprisals they were in turn subjected

From the year 1869, the date of the establishment of the Russian military settlement at Krasnovodsk on the east shore of the Caspian the wave of Russian conquest has gradually swept eastwards along the northern frontier of Persia until it has for the moment stopped at the outer most border of the Akhal Turcoman country, which was incorporated in 1881 by Russia as the result of the defeat of that tribe at Geok Tepe Among the districts still farther east, to which the Russians give the name of Eastern Turcomania, is that of the Merv Tekke Turcomans, kinsmen of the Akhal Tekkes, the most recent of Russia's subjects The district of the Merv Tekkes may be taken to be that included between the lower Murghab below Yulutan, where the river enters the plain, and the Persian frontier from Sarakhs to Gawars

A reference to the map will show the strategical importance of this district, situated at the point of meeting of two lines, of which one is the strategic line of Russian advance on Herat from Krasnovodsk to Sarakhs, and the other the strategic line of advance on the same place from Tashkend through Bokhara The capital of the district is, moreover, the crossing point of the Herat Khiva and Meshed Bokhara trade routes

Consequently this district a solitary oasis in a vast desert, guarantees to its possessor the command of an important avenue between north and south, and, in the event of its falling into Russian hands, will give that power in addition a valuable link in the chain of connexion between her recent acquisitions on the Persian frontier and those in Turkestan, the forging of which has been persistently advocated by Russian writers for years past One of these, Colonel Venukoff, frankly admits that it is the political results—"the consolidation of friendly relations with the Turcomans —and not commercial interests merely, that are primarily looked to, and openly states that the forward movement in Central Asia "cannot end otherwise than by the annexation to Russia of the whole of Turan"

Whether by design or by the force of circumstances, the recommendations of those writers have been translated into facts, and Russia with her advanced post at Askabad is now within 400 miles of Herat, which Sir Henry Rawlinson designates as the key of India The occupation of the Merv Tekke country would bring Russia to within 250 miles of Hera. From Askabad she is in connexion with the Caspian by a good line of communication, part of which from the sea to Kizil Arvat) is by rail, and hence facilities are offered for bringing up not only the resources of the Caucasus but of the whole of European Russia While Russian troops are within 400 miles of Herat, the British troops at Quetta are more than 500 miles from Herat[1]

These remarks serve to explain the very natural suspicion with which Great Britain has regarded the occupation one after another of important strategical points along that route by which alone Russia can strike at India,—the same line by which Napoleon meditated a Russo French invasion in the early part of this century

In the matter of Merv and the neighbouring Turcoman districts diplomacy has not been idle As early as 1869, when an interchange of opinions was taking place between the Russian and British Governments with respect to the demarcation of a neutral zone between the two empires, Great Britain objected to the Russian proposal that this zone should be Afghanistan, "because of the near approach to India that would be thereby afforded to Russian troops from the direction of the Kara kum, the home of the Turcomans, of which Merv is the central point In the following year a Russian diplomatist remarked to the British ambassador at St Petersburg when discussing the Afghan frontier, that great care would be required in tracing a line from Khoja Saleh on the Oxus to the south as Merv and the country of the Turcomans were becoming "commercially important About the same time Russia intimated that, if the amir of Afghanistan claimed to exercise sovereignty over the Tekkes, his pretensions could not be recognized After the Russian campaign against Khiva in 1873 and the subsequent operations against the Turcomans, the English foreign secretary early in 1874 called attention "to the fears expressed by the amir of Afghanistan as to the complications in which he might become involved with Russia were the result of a Russian expedition against Merv to be to drive the Turcomans to take refuge in the province of Badghees in Herat In reply to this communication Prince Gortschakoff repeated the assurance that the imperial Government had no intention of sending any expedition against the Turcomans or of occupying Merv In 1875 the operations of General Lomakin on the northern frontier of Persia led to representations being made by the British ambassador at the court of St Petersburg To these Russia replied that the czar had no intention of extending his frontiers on the side of Bokhara or on the side of Krasnovodsk Notwithstanding the oft repeated assurances to the contrary large annexations have been since made in Turcomania by the Russians, and these proceedings, clearly indicating the persistent prosecution of a concerted plan have naturally tended to disturb the harmonious relations which should subsist between the two great civilizing powers of the East

Settlements and Inhabited Centres—Of towns or even villages, fixed centres of habitation, there are none, according to Mr O Donovan, the latest European traveller to Merv The present political and military capital of Merv is Koushid Khan Kala, a fort which serves rather as a place of refuge against sudden attacks than as a habitation It is situated on the east bank of the most westerly branch of the Murghab, about 25 miles below the dam at Porsa Kala In form it is oblong, measuring 1¾ miles long by ¾ mile broad, is constructed entirely of earth, revetted on the exterior slope with sun-dried brick, the ramparts are 40 feet high, and are 60 feet at the base The fort is built in a loop of the river, which protects it on two sides between it and the river is an "obah,' or nomad village of huts and tents, some thousand in number, disposed in rows, but there is no town or settlement

Twenty five miles east of Koushid Khan Kala lie the ruins of the Greek city of Antiochia Margiana, showing traces of a high civilization According to Strabo (xi 2) the Merv oasis at this period was surrounded with a wall measuring 1500 stadia (185 miles) Mr O Donovan found the trace of the fort of Iskander to have been quadrangular, with a length of side of 900 yards This was probably the fort built by Alexander, about 328 B C, on his return from

---

[1] Concurrently with the consolidation of her position in Turcomania, Russia has of late been showing less military activity on the side of her Turkestan district It is probable that her recent explorations at the sources of the Oxus have demonstrated the impracticability of directing any offensive movement against India from that side. Hence the line of strategical advance has been shifted from Tashkend to Tiflis

Sogdiana after the capture of Bessus. The city was destroyed in 666 A.D. by the Arabs, who built a new one, afterwards known as Sultan Sanjar, about 1000 yards away, and occupying an area, according to Mr O'Donovan, of about 600 yards square. The towers are still extant, and inside can be seen the ruins of a most elaborate tomb, in which the supposed bones of Sultan Sanjar are enshrined. It has always been a place of pilgrimage for the faithful. Not far to the south west lies the site of the last city of Merv, that which existed up to a hundred years ago, when it was laid waste by the Bokharians. It bears the name of its gallant defender Bairam Ali.

These three ruins are all that remain of that which flourished of yore as "sovereign of the universe."

At the time of the visit of Burnes, Abbott, Shakespear, and Taylour Thomson, about the fourth decade of the century, Merv was under the jurisdiction of Khiva, and the administrative centre was at Porsa Kala, where the dam is situated. This place is now also a waste of mud ruins, uninhabited.

Rivers.—The Heri rud (or Tejend, as the river is named below Sarakhs) runs a course of some 280 miles within Afghan borders. On reaching the Persian frontier it turns north and forces a channel through the mountain chain near Sarakhs. Beyond Sarakhs the river is Turcoman on both banks, runs close to the Khelat mountains, and in the latitude of Askabad loses itself in the marshes formed by the spring floods. It is probably the Ochus of ancient geography, which watered Nissa, once the capital of Parthia, and joined the Oxus just before the latter river disembogued into the Caspian (Rennell's *Herodotus*). The Tejend is fordable at all points below Sarakhs except in the early spring after the melting of the snows. On the road from Meneh to Merv the river is sluggish, 50 yards wide and 4 feet deep in February. The river bed is sunk 12 to 15 feet below the level of the surrounding country, and has immense quantities of drift wood on its banks; trees and luxuriant herbage clothe the immediate borders. At midsummer the river runs nearly dry, and does not reach Sarakhs. The Kashaf rud, which flows near Meshed, is one of its chief affluents.

The Murghab takes its rise in the northern slopes of the Paropamisus, and runs parallel to the Heri rud at a distance of 70 miles from it. On this river lies the plain or oasis of Merv, irrigated by means of an elaborate system of dams and canals cut from the main river. Beyond the limits of the oasis the Murghab "hides its streams in the sand," like the Tejend. The river at Porsa Kala (near the principal dam) is 80 yards wide, at Koushid Khan Kala 30 to 40 yards wide. In summer it is much swollen by the melting of the snows, and its stream is then barely fordable. The water is yellow in colour from suspended matter.

Formerly a great deal of the country, now a waste, between the two rivers was also cultivated by the agency of water derived from canals cut from the Tejend. These canals extended to Kuchh Kum in the desert, rendering the journey between the two rivers much easier than in the present day. From the Murghab was also cut, among others, the Kara-i-ab canal, which ran for a distance of 40 miles towards the Tejend. Recent explorers affirm that there is no reason why these canals should not be again filled from those rivers, when the intervening country, "an argillaceous expanse" (O'Donovan), would become culturable.

Communication.—Merv is surrounded on all sides by desert. On the north, west, and east this desert is sandy and arid; water is exceedingly scarce, the wells being sometimes 60 or 70 miles apart and easily choked. To the south of Merv, between the rivers Murghab and Tejend, there are traces of past cultivation, of irrigating canals, and of considerable settlements. Between the Tejend and Askabad the road lies through a populous well cultivated country (Persian territory) by way of Kahka and Lutfabad.

There are no roads in Merv,—nothing but mere tracks. Many wide and deep irrigating canals have to be crossed; bridges are few and bad. The inhabitants cross by inflated skins.

The following tracks lead to the Persian frontier from Merv:—(1) *via* Mahmur or Chungul to Lutfabad—eight days on camels; (2) *via* Shahidli to Mehna—120 miles; (3) *via* Shahidli to Fort Cherkeshli and Meshed,—for 85 miles between the Murghab and Tejend there is scarcely any water; (4) *via* Sarakhs to Meshed, 9 or 10 marches for camels, and, according to Petrusevitch, without water between Merv and Sarakhs—120 miles.

To the Afghan frontier lead (1) the track *via* Sarakhs and up the Heri rud to Herat—fit for a coach according to Sir Charles MacGregor and Mr Lessar; and (2) a practicable track, used by Abbott and Shakespear, up the Murghab and Kushk rivers.

To the Oxus in Bokharian territory lead several tracks, the chief of which is that to Charjui—nine marches for camels. Water is scarce.

To Khiva by the direct track is 360 miles. Water is scarce.

Population.—The Turcomans, according to Sir Henry Rawlinson and others, are descendants of the Ghuz or Komani, a race of Turks who migrated westward from their homes in the Altai before the Christian era, and penetrated even to the Danube. From subsequent intermixture with Persian and Caucasian peoples they exhibit variations from the true Tartar type. According to Baron de Bode the Turcoman closely resembles both in appearance and in speech the Nogai Tartar and the Tartar of Kasan on the Volga.

They are an independent race, as wild and free as their native desert, brave and very impatient of control—"Wild warriors in stormy freedom bred" (Moore). They have a very evil reputation for brigandage and murder, so much so that the Bokharians and Khivans have a proverb—"If you meet a viper and a Mervi, commence by killing the Mervi and then despatch the viper." Of late years a change for the better has taken place, and recent travellers among them state that the Mervis show an inclination to lead a more settled life and to establish an elementary form of government (Medjliss), and that it is no longer accounted an honour among them to kill their neighbours. Opium smoking and arrack drinking are apparently widespread vices (O'Donovan); at the same time they are described as clever and intelligent.

The Merv Tekkes (like the Akhal Tekkes) are classed in two great divisions—the Toktamish and the Otamish. Each of these divisions consists of two clans, and each clan is subdivided into families. The two clans of the Toktamish are called Beg and Wakil; those of the Otamish, Suchmuz and Bukshi. The clans of Beg and Wakil are the most powerful, and occupy that part of the oasis which lies on the right or east bank of the Murghab. The Suchmuz and Bukshi have their tents on the left or west bank.

There is no machinery of government, and no taxes are levied. Whatever government there be is of a patriarchal nature. Each family has a *kethkhoda* (patriarch), who represents the family in matters of policy, but can only act in accordance with the wishes of the clan. The *aksakals* or grey beards are also useful in settling intertribal disputes, but they are tolerated only so long as they do not act in opposition to the tribesmen. For external affairs and in time of war the *kethkhodas* exercise a certain amount of power. The authority of *kethkhodas* and *aksakals* is, however, overridden by the laws of custom or usage (*deb*) and the less respected laws of religion. The injunctions of deb are paramount. It sanctions the *alaman*, or plundering raid, and in general regulates the Turcoman's daily life; its prescriptions are more binding than those of the Koran.

The Tekkes marry young. The father purchases for his twelve year old son a child wife for 500 to 2000 krans (£20 to £80). A young widow of twenty five is much more valuable, but a woman over forty is not worth the price of a camel. On the conclusion of the bargain, the priest reads a prayer from the Koran and the marriage becomes valid.

The dress of the men consists of a long tunic of coarse crimson silk reaching below the knees, with a white sash through which is stuck a dagger; an outer robe of brown camel hair cloth, a huge sheepskin hat, trousers and slippers or amber coloured knee boots, complete the costume. The women are exceedingly fond of trinkets, rings, and amulets, which accompany their movements with a sound as it were of bells. Their dress consists of the same red silk robe as the men wear, with a sash round the waist, and high heeled boots, red or yellow.

The religion is Sunni Mohammedan; their language Jagatai or Oriental Turk.

The numbers of Merv Tekkes on the Murghab and Tejend are variously estimated, but may be stated approximately at 40,000 tents, including 5000 tents of the Salor tribe. These 40,000 tents represent a population of 200,000 to 250,000 souls. The Salors and Sariks at Yulutan and Panjdeh, higher up the Murghab, are given at 11,000 tents, or some 60,000 souls.

Products, Arts, and Manufactures.—The country in all times has been renowned throughout the East for its fertility. Strabo tells us "that it was not uncommon to meet with a vine whose stock could hardly be clasped by two men with outstretched arms, while clusters of grapes might be gathered two cubits in length. The Arab traveller Ibn Haukal, writing in the 10th century, remarks that "the fruits of Merv are finer than those of any other place, and one cannot see in any other city such palaces with groves and streams and gardens." A local proverb says, "Sow a grain to reap a hundred." All cereals and many fruits grow in great abundance.

The Turcomans possess a famous breed of horses,—not prepossessing in appearance, being somewhat leggy and long in the back and neck, but capable of accomplishing long distances—50 or 60 miles—for several days in succession and with very little food. Their great peculiarity appears to be their hairlessness; the coat is very fine, the mane and tail very scanty. This breed of horses as well as the wealth of the Merv Tekkes in camels and flocks, is fast disappearing.

The Turcomans are noted as excellent workers in silver and as armourers, and their carpets are superior to Persian. They also make felts and a rough cloth of sheep's wool.

One of the chief occupations of the male sex is the repair of the dams and the clearing of the canals upon the efficiency of which their existence is dependent. The services of a large number of workmen are always held in readiness for the purpose. In 1878 the unusual mass of water in the Murghab carried away the dam and the drying up of some of the canals nearly led to a failure of the crops.

Climate.—The position of Merv, in the midst of sandy deserts in the heart of Asia, makes the climate in the heat of summer most oppressive. The least wind raises clouds of fine sand and dust, which fill the air, render it so opaque as to obscure the noonday sun, and make respiration difficult. In winter the climate is very fine. Snow falls rarely and melts at once.

History.—The name Merv, or some similar form, occurs at a very early period in the history of the Aryan race. Under Mouru we find it mentioned with Bakhdi (Balkh) in the geography of the Zend Avesta (*Vendidad*, fargand i. ed. Spiegel), which dates probably from a period anterior to the conquest of Bactria by the Assyrians, and therefore at least one thousand two hundred years before the Christian era. Under the name of Margu it occurs in the cuneiform inscriptions of Darius Hystaspis, where it is referred to as forming part of one of the satrapies of the ancient Persian empire (*Inscriptiones Behistani*, ed. Kossowicz). It afterwards became a province (Μαργιανή) of the Græco-Syrian, Parthian, and Persian kingdoms. On the Margus—the Epardus of Arrian and now the Murghab—stood the capital of the district, Antiochia Margiana, so called after Antiochus Soter, who rebuilt the city founded by Alexander the Great. About the 5th century, during the dynasty of the Sasanids, Merv was the seat of a Christian archbishopric of the Nestorian Church. In the middle of the 7th century the flood of Arab conquest swept over the mountains of Persia to the deserts of Central Asia. Merv was occupied 666 A.D. by the lieutenants of the caliph Othman, and was constituted the capital of Khorasan. From this city as their base the Arabs, under Kuteibe bin Muslim, early in the 8th century brought under subjection Balkh, Bokhara, Ferghana, and Kashgaria, and penetrated into China as far as the province of Kan-su. In the latter part of the 8th century Merv became obnoxious to Islam as the centre of heretical propaganda preached by Mokannah (Haschem ben Hakem), the "veiled prophet of Khorasan," who claimed to be the incarnation of the Deity. In 874 Arab rule in Central Asia came to an end. During their dominion Merv, like Samarkand and Bokhara, became one of the great schools of science, and the celebrated historian Yakut studied in its libraries. About 1037 the Seljukian Turks crossed the Oxus from the north and raised Toghrul Beg, grandson of Seljuk, to the throne of Persia, founding the Seljukian dynasty with its capital at Nishapur. A younger brother of Toghrul, Daoud, took possession of Merv and Herat. Toghrul was succeeded by the renowned Alp Arslan (the great lion), whose sway was so vast that, according to tradition, no fewer than twelve hundred kings, princes, and sons of kings and princes did homage before his throne. Alp Arslan was buried at Merv. It was about this time that Merv reached the zenith of her glory. During the reign of Sultan Sanjar of the same house, towards the middle of the 11th century, Merv was overrun by the Turcomans of Ghuz, and the country was reduced to a state of misery and desolation. These Turcomans, the ancestors of the present tribes of Turcomania, were probably introduced into the country by the Seljukian Turks as military colonists. They formed the van of their armies, and rendered efficient service so long as the dynasty lasted, and afterwards took part in the wars of Tamerlane.

In 1221 Merv opened its gates to Toolai, son of Jenghiz, khan of the Mongols, on which occasion the inhabitants, to the number of 700,000, are said to have been butchered. From this time forward Merv, which had been the chief city of Khorasan, and was popularly supposed to contain a million inhabitants, commenced to languish in obscurity. In the early part of the 14th century Merv was again the seat of a Christian archbishopric of the Eastern Church. On the death of the grandson of Jenghiz Khan, Merv became included in the possessions of Toghluk Timur Khan (Tamerlane), in 1380. In 1505 the decayed city was occupied by the Uzbeks, who five years later were expelled by Ismail Khan, the founder of the Suffavean dynasty of Persia. Merv thenceforward remained in the hands of Persia until 1787, when it was attacked and captured by the emir of Bokhara. Seven years later the Bokharians razed the city to the ground, broke down the dams, and converted the district into a waste. About 1790 the Sarik Turcomans pitched their tents there. When Sir Alexander Burnes traversed the country in 1832, the Khivans were the rulers of Merv, the nomad population being subject to them. About this time the Tekke Turcomans, then living at Orazkala on the Heri-rud, were forced to migrate northward in consequence of the pressure from behind of the Persians. The Khivans contested the advance of the Tekkes, but ultimately, about the year 1856, the latter became the sovereign power in the country, and have ever since resisted all attempts at reconquest.

Authorities.—Besides the standard travels of Wolff, Ferrier, Vambéry, Burnes, Abbott, Mouravieff, and others, the following works and papers of more recent date may be consulted with advantage:—Sir H. Rawlinson's *England and Russia in the East*; O'Donovan's correspondence with the *Daily News*, 1880-81; O'Donovan's "Merv," *Proc. Roy. Geog. Soc.*; Col. Stewart's "Country of the Tekke Turcomans," *Proc. Roy. Geog. Soc.*, with excellent map; "The New Russo-Persian Frontier," 1881, *Proc. Roy. Geog. Soc.*; Girard de Rialle, *Mémoire sur l'Asie Centrale*; Sir H. Rawlinson, "Road to Merv," *Proc. Roy. Geog. Soc.*; Col. Baker's *Clouds in the East*; Captain Napier's Reports, *Jour. Roy. Geog. Soc.*; Hutton's *Central Asia*; Marvin's *Merv*; Col. Potto's *Steppe Campaigns*; Sir Charles MacGregor's *Journey through Khorassan*; Boulger's *England and Russia in Central Asia*; Captain Butler's *Communications to the Public Press*; Lessar's Journeys, *Proc. Roy. Geog. Soc.*; O'Donovan's *Merv Oasis*; Papers on the Turcomans, &c., by Col. Petrusevitch, *Proc. Imp. Russ. Geog. Soc.*, Caucasus section; Col. Grodekoff's *Journey from Tashkend to Persia*, 1880; Captain Kuropatkin's *Turcomania*, 1880; Col. Venukoff's *Progress of Russia in Central Asia*, 1877, and other papers by the same author; Col. Kostenko's Turkestan, *R. U. S. Instn.*; Schuyler's *Turkistan*; correspondence on Central Asia presented to parliament, &c. (F. C. H. C.)

MÉRYON, Charles (1821-1868). The name of Méryon is associated with that spirited revival of etching in France which took place in the middle of the 19th century,—say from 1850 to 1865,—but it is rather by the individuality of his own achievements, and the strength of his artistic nature, than by the influence he exercised that Méryon best deserves fame. No doubt his work encouraged others to employ the same medium of expression, and so great was his own perfection of *technique* that he may well have been made a model; but, after all, the medium he selected, and in which he excelled, was but the accident of his art; he was driven to it in part by stress of circumstances—by colour blindness; and, even with colour blindness, his extraordinary certainty of hand and his delicate perception of light, aided by his potent imagination, would have made him a great draughtsman not alone upon the copper.

Charles Méryon was born in Paris in 1821. His father was an English physician, his mother a French dancer. It was to his mother's care that Méryon's childhood was confided. She was supplied with money, and she gave the boy passionate affection, if not a wise training. But she died when he was still very young, and Méryon in due time entered the French navy, and in the corvette "Le Rhin" made the voyage round the world. He was already draughtsman, for on the coast of New Zealand he made pencil drawings which he was able to employ, years afterwards, as studies for etchings of the landscape of those regions. The artistic instinct developed, and, while he was yet a lieutenant, Méryon left the navy. Finding that he was colour blind, Méryon determined to devote himself to etching. He entered the work room of one Bléry, from whom he learnt something of technical matters, and to whom he always remained grateful. Méryon was by this time poor. It is said that he might have had assistance from his kindred, but he was too proud to ask it. And thus he was reduced to the need of executing for the sake of daily bread much work that was wholly mechanical and irksome. Resolutely, though unwillingly, he became the hack of his art, doing frequently, from the day when he was first a master of it to the day when insanity disabled him, many dull commissions which paid ill, but paid better than his original works. Among learner's work, done for his own advantage, are to be counted some studies after the

Dutch etchers such as Zeeman and Adrian van de Velde. Having proved himself a surprising copyist, he proceeded to labour of his own, and began that series of etchings which are the greatest embodiments of his greatest conceptions—the series called "Eaux fortes sur Paris." These plates, executed from 1850 to 1854, are never to be met with as a set, they were never expressly published as a set. But they none the less constituted in Méryon's mind an harmonious series. For him their likenesses and their contrasts were alike studied, they had a beginning and an end, and their differences were lost in their unity.

Besides the twenty two etchings "sur Paris" characterized below, Méryon did seventy two etchings of one sort and another,—ninety four in all being catalogued in Wedmore's *Méryon and Meryon's Paris*, but these include the works of his apprenticeship and of his decline, adroit copies in which his best success was in the sinking of his own individuality, and dull and worthless portraits chiefly of forgotten celebrities. Yet among the seventy two prints outside his professed series there are at least a dozen that will aid his fame. Three or four beautiful etchings of Paris do not belong to the series at all. Two or three etchings, again, are devoted to the illustration of Bourges, a city in which the old wooden houses were as attractive to him for their own sakes as were the stone built monuments of Paris. But generally it was when Paris engaged him that he succeeded the most. He would have done more work, however,—though he could hardly have done better work,—if the material difficulties of his life had not pressed upon him and shortened his days. He was a bachelor, unhappy in love, and yet, it is related, almost as constantly occupied with love as with work. The depth of his imagination and the surprising mastery which he achieved almost from the beginning in the technicalities of his craft were appreciated only by a few artists, critics, and connoisseurs, and he could not sell his etchings, or could sell them only for about 10d a piece. The fact that his own original work was of incalculably greater value than his best copies of his most celebrated forerunners had not yet impressed itself upon anybody. Disappointment told upon him, and, frugal as was his way of life, poverty must have told on him. He became subject to hallucinations. Enemies, he said, waited for him at the corners of the streets, his few friends robbed him or owed him that which they would never pay. A very few years after the completion of his Paris series, he was lodged in the madhouse of Charenton. Its order and care restored him for a while to health, and he came out and did a little more work, but at bottom he was exhausted. In 1867 he returned to his asylum, and died there in 1868. In the middle years of his life, just before he was placed under confinement, he was much associated with Bracquemond and with Flameng,—skilled practitioners of etching, while he was himself an undeniable genius,—and the best of the portraits we have of him is that one by Bracquemond under which the sitter wrote that it represented "the sombre Méryon with the grotesque visage." And it did.

There are twenty two pieces in the Eaux fortes sur Paris. Some of them are insignificant. That is because ten out of the twenty two were destined as headpiece, tailpiece, or running commentary on some more important plate. But each has its value, and certain of the smaller pieces throw great light on the aim of the entire set. Thus, one little plate—not a picture at all—is devoted to the record of verses made by Meryon, the purpose of which is to lament the life of Paris. The misery and poverty of the town Meryon had to illustrate, as well as its splendour. The art of Meryon is completely misconceived when his etchings are spoken of as views of Paris. They are often "views," but they are so just so far as is compatible with their being likewise the visions of a poet and the compositions of an artist. It was an epic of Paris that Meryon determined to make, coloured strongly by his personal sentiment, and affected here and there by the occurrences of the moment,—in more than one case, for instance, he hurried with particular affection to etch his impression of some old world building which was on the point of destruction. Nearly every etching in the series is an instance of technical skill, but even the technical skill is exercised most happily in those etchings which have the advantage of impressive subjects, and which the collector willingly cherishes for their mysterious suggestiveness or for their pure beauty. Of these, the Abside de Notre Dame is the general favourite, it is commonly held to be Meryon's masterpiece. Light and shade play wonderfully over the great fabric of the church, seen over the spires of the river. As a draughtsman of architecture, Meryon was complete. his sympathy with its various styles was broad, and his work on its various styles unbiassed and of equal perfection—a point in which it is curious to contrast him with Turner, who, in drawing Gothic, often drew it with want of appreciation. It is evident that architecture must enter largely into any representation of a city, however much such representation may be a vision, and however little a chronicle. Besides, the architectural portion even of Meryon's labour is but indirectly imaginative, to the imagination he has given freer play in his dealings with the figure, whether the people of the street or of the river or the people who, when he is most frankly or even wildly symbolical crowd the sky. Generally speaking, his figures are, as regards draughtsmanship, "landscape painter's figures." They are drawn more with an eye to grace than to correctness. But they are not "landscape painter's figures" at all when what we are concerned with is not the method of their representation but the purpose of their introduction. They are seen then to be in exceptional accord with the sentiment of the scene. Sometimes, as in the case of La Morgue, it is they who tell the story of the picture. Sometimes, as in the case of La Rue des Mauvais Garçons,—with the two passing women bent together in secret converse,—they at least suggest it. And sometimes, as in l'Arche au Pont Notre Dame, it is their expressive gesture and eager action that give vitality and animation to the scene. Dealing perfectly with architecture, and perfectly, as far as concerned his peculiar purpose, with humanity in his art, Meryon was little called upon by the character of his subjects to deal with Nature. He drew trees but badly, never representing foliage happily, either in detail or in mass. But to render the characteristics of the city, it was necessary that he should know how to pourtray a certain kind of water—river water mostly sluggish—and a certain kind of sky—the grey obscured and lower sky that broods over a world of roof and chimney. This water and this sky Meryon is thoroughly master of, he notes with observant affection their changes in all lights.

Méryon's excellent draughtmanship, and his keen appreciation of light, shade, and tone, were, of course helps to his becoming a great etcher. But a living authority, himself an eminent etcher, and admiring Meryon thoroughly, has called Meryon by preference a great original engraver,—so little of Meryon's work accords with Mr Haden's view of etching. Meryon was anything but a brilliant sketcher, and, if an artist's success in etching is to be gauged chiefly by the rapidity with which he records an impression, Meryon's success was not great. There can be no doubt that his work was laborious and deliberate, instead of swift and impulsive, and that of some other virtues of the etcher—"selection" and "abstraction" as Mr Hamerton has defined them—he shows small trace. But a genius like Meryon is a law unto himself, or rather in his practice of his art he makes the laws by which that art and he are to be judged. He was a great etcher, and by his most elaborate labour he seemed somehow to ensure the more completely for his picture that virtue of unity of impression which, it may well be admitted, oftener belongs to rapid than to deliberate work. In Meryon's etchings the hand work never seems to be in arrear of the thought. As long as the hand work must continue, the thought and passion are retained. Meryon knows the secrets of his craft as well as did the older masters of it, but he turns them to his own purposes. He is unexcelled in strength and in precision, nor is he often rivalled in delicacy. These qualities, and others more distinctly technical, which it would take too long to insist on here, students find in his etchings. But the incommunicable charm of Meryon's prints and their lasting fascination are due to the fact that behind all technical qualities, and as their very source and spring, there lies the potent imagination of the artist, poetical and vivid, directing him what to see in his subject, and how to see it. (F. WE.)

MESCHERYAKS, or **MESCHERS**, a people inhabiting eastern Russia. Nestor regarded them as Finns, and even now part of the Mordvinians (of Finnish origin) call themselves Meschers. Klaproth, on the other hand, supposed they were a mixture of Finns and Turks and the Hungarian traveller Reguli discovered that the Tartarized Meschers of the Obi closely resembled Hungarians. They formerly occupied the basin of the Oka (where the town Meschersk, now Meschovsk, has maintained their name) and of the Sura, extending north-east to the Volga. After the conquest of the Kazan empire by Russia, part of them migrated north eastwards to the basins of the Kama and Byelaya, and thus the Meschers divided into two branches The western branch became Russified, so that the Mescheryaks of the governments of Penza, Saratoff, Ryazan, and Vladimir have adopted the customs, language, and religion of the conquering race, but their ethnographical characteristics can be easily distinguished in the Russian population of the governments of Penza and Tamboff The eastern branch has taken on the customs, language, and religion of Bashkirs, with whom their fusion is still more complete They can be distinguished from their neighbours only by their more peaceful character This Bashkir Mescheryak branch was estimated by Rittich in 1875 to number 138,000 They make 6 per cent of the population of the government of Upa, and 22 per cent in the district of Birsk The number of the western Mescheryaks is unknown, and could hardly be estimated on account of their mixture with Russians It is only in the government of Penza that they have maintained their national features, there they make 3 per cent of the population

MESCHOVSK, a district town of Russia, in the government of Kaluga, 45 miles to the south west of the capital of the province It is an old town supposed to date from the 13th century, and it is often mentioned in Russian annals under the names of Mezetsk, Mezechevsk, or Meschorsk About the end of the 14th century it was embraced in Lithuania, and it was ceded to the Moscow "great principality' in 1494 It was often pillaged by Tartars in the 16th century, and during the great disturbances of 1610 all its inhabitants were killed by the Zaporoghi Cossacks, and the fort was taken by Poles, who returned it to Russia only after the treaty of Deulin The country round Meschovsk is not fertile, but, from its position on old established routes to the south, the town has become a centre of considerable trade Its annual fair, which takes place on the grounds of the very old Petrovsk monastery, is important to the surrounding districts for the export sale of horses, grain, hemp, hempseed oil, and coarse linen, and for the import trade in cottons, woollens, and earthen and glass wares, the whole turn over reaching about £100,000 Population, 7400

MESHED (properly Mesh hed, *i e*, "place of martyrdom, "shrine), a city of northern Persia, capital of Khorásán, 472 miles east of Tehrán, 201 miles north west of Herat, 36° 17 40 N, 52 35 29 E, lies on a plain watered by the Keshaf rud, a tributary of the Heri rud and is surrounded by mud walls 4 miles in circumference, with a dry ditch 40 feet deep at some points, which could be flooded from the neighbouring reservoir and watercourses Within this enclosure is a strong citadel, with good walls 25 feet high, residence of the prince governor of Khorasán There are five gates, from one of which, the Bala Khiabán, the Khíabán main street runs right through the city, forming a fine boulevard planted with plane and mulberry trees, and with a stream of dirty water running down its whole length In the centre is an open parallelogram 160 yards by 75, encircled by double storied cloisters, and pierced on the long side by a high arched porch leading directly to the great mosque, whose gilded dome rises above the shrine of the famous Imám Rizá[1] The marble tomb of the saint, which is the most venerated spot in the whole of Persia, and yearly visited by from 80,000 to 100,000 pilgrims, is surrounded by a silver railing, and approached by a flight of inlaid marble steps Eastwick, the only European before O Donovan who penetrated as far as the parallelogram, describes the mosque as large enough to contain three thousand people It is flanked by two gilded minarets, one of which, 120 feet high, is extremely beautiful, with an exquisitely carved capital, built by Shah Abbás The façade is entirely covered with blue and white enamelled tiles To the mosque are attached as many as two thousand attendants and retainers of all sorts, including no less than five hundred mollahs Beyond the dome is Gauhar Sháh's handsome mosque, surmounted by an immense blue dome, and also flanked by two minarets In the main street is a public kitchen supported by the enormous revenues of the shrine, where eight hundred devotees are daily supplied with food gratuitously The only other notable buildings in the place are some colleges and twenty two caravanserais, one of which is of great size Meshed does a considerable local and transit trade to the yearly value of about 600,000 tománs, and its bazaars are always well stocked with silks, velvets, felts, cottons, shawls, carpets, lacquer work, lambskins, hardware, glass, china, and other goods from South Persia, India, Turkestan, and Russia The European trade is now entirely controlled by Russia, and European manufactured articles are mostly all from that country The chief manufactures are silk, satin, velvet, and checked cotton fabrics, carpets, shawls, noted sword blades, shagreen, and turquois jewellery Within the enclosures are extensive cemeteries far exceeding the local requirements, large numbers of the faithful being brought from all parts of the Shí'a world to be buried in the vicinity of Rizá's shrine under the belief that their eternal salvation is thereby ensured

Some 10 miles west of Meshed is a powder factory, formerly under Colonel Dolmage where powder of excellent quality is produced The district, although fertile, does not produce sufficient for the inhabitants, so that much grain has to be imported from Kurdistan and Nishapur The climate is very severe in winter, with much snow, in summer it is less sultry than might be expected, the temperature ranging from 76° F to 90° or 92° F and in exceptional years 94° to 98° F The population is variously estimated at from 45,000 (Connolly) and 60,000 (Ferrier) to 80,000 and 100,000 (Eastwick) The settled residents, exclusive of pilgrims and foreign traders are estimated by O Donovan at 50,000

The main caravan routes from Khiva, Bokhara, Samarkand and Herat converge at Meshed whence lines of traffic radiate to Kuchan for the Atrek valley and the Caspian, to Nishapur and Bostam for Tehran, to Tabas for Isfahan, to Khaf for Sistan and Kirman It thus occupies a position in north eastern Persia analogous to that of Tabriz in the north west

MESHED ALI, *i e*, the shrine of the "martyr" Ali, is a town of Asiatic Turkey, province of Baghdad, 50 miles south of Kerbela, close to the ruins of Kufa, and 2 miles west of the Hindiye branch of the Euphrates, the reputed burial place of the caliph Ali[2] It stands on the east scarp of the Syrian desert, and is enclosed by nearly square brick walls flanked by massive round towers dating from the time of the caliphs Under the gilded dome of the great mosque, which occupies the centre of the town, is the shrine of Ali, which is held by the Shí'a as at least as holy as the Kaaba itself Any Moslem buried within sight of the dome being certain of salvation, large numbers of bodies are yearly sent from all parts for interment here Besides the mosque with its richly decorated façade, the only noteworthy building is a good bazaar supplied from Baghdad and Basra The town itself, which Lady Anne

---

[1] Alí Riza (or el Rida) the eighth imam of the Shi'a is the Ali ibn Musa from whom the party of Alides had such hopes under the caliphate of Mamun (see MOHAMMEDANISM) He died at Tus 818 A D and was buried by Mamun's orders in the vicinity of that town beside the grave of Harun el Rashid To the Alides he was a martyr, being believed to have been poisoned by the caliph Ibn Batuta who describes both shrines (iii 77 *sq*) tells how the pious visitors to the shrine of Ali ibn Musa used to spurn with their feet the tomb of Rashid In his time a considerable town had been formed around the shrine under the name of Meshhed el Rida and ultimately the new town eclipsed the older city of Tus

[2] Whether the place really contains the grave of Ali was long disputed and the story given in defence of its claims is doubtless apocryphal The dome was built under the Abbasids, and the resting-place of the caliph unknown or concealed under the Omayyads (Ibn Haukal, p 163)

Blunt describes as "an ideal Eastern city, standing in an absolute desert, and bare of all surroundings but its tombs," consists of narrow gloomy streets lined by houses closely packed together The locality is properly named Najaf, and gives its name to the neighbouring lake, a large depression filled by an eruption of the river, and ranging from 6 to 20 feet in depth The accumulated treasures of the shrine were carried off by the Wahhábites when they captured this place early in the present century The population is estimated at 7000, including several Indian Mohammedans under the protection of the British resident at Baghdad

The aspect of the shrine in the 14th century is described by Ibn Batuta, i 414 *sq* A plan of the town and description of its splendour before the Wahhabites pillaged it is given by Niebuhr See also Ibn Jubair p 214, P Teixeira, *Itin*, cap iv

MESHED HOSEIN, properly MESHHED HOSEIN See KERBELA, vol xiv p 48

MESMER MESMERISM See vol xv p 277

See Plate VIII

MESOPOTAMIA, the "country between the rivers, is a purely geographical expression, the countries which it comprehends never having formed a self contained political unity [1] It was first introduced by the Greeks at or after the time of Alexander, but probably had its origin in the earlier Aramæan name *beth nahrîn* (the country between the rivers), to which again corresponds the Biblical *Aram Naharaym* As early as 700 B C "the country of two rivers' is mentioned on the Egyptian monuments under the name Naharina, but no such designation appears in the cuneiform inscriptions (though the territory formed part of the Assyrian as it afterwards did of the Persian empire) The most settled period in the history of Mesopotamia was probably under Persian Greek rule Xenophon applies the name Syria to the extremely fertile district which he traversed after having crossed the Euphrates at Thapsacus The country beyond the Araxes (Chaboras ?) he calls Arabia, —a desert region in which his army had to suffer great hardships until it reached the "gates of Arabia Even in later times Mesopotamia was included under the name Assyria, or was reckoned part of Babylonia

These statements of Xenophon already indicate a demarcation of the territory afterwards called Mesopotamia, as well as its division into two sections The fertile portion, inhabited by agricultural Aramæans, stretched from the Euphrates to the Chaboras, the desert portion, the home of wandering tribes, extended to the Tigris It would be rash, however, to conclude from this that Mesopotamia designated the whole territory between the Euphrates and Tigris, indeed it is possible that *Aram Naharaym*, the Aram of the country of the two rivers, originally meant only the main portion of the fertile country inhabited by Syrians In this case the two boundary rivers must have been, not the Euphrates and the Tigris, but the Euphrates and the Chaboras After the final occupation of the country by the Romans (156 A D), the political province of Mesopotamia was practically confined to this more limited district Though in ordinary usage the Euphrates and Tigris are considered as the two rivers which bound Mesopotamia, the one bank of the river cannot be geographically separated from the other, and consequently narrow strips of country on the right bank of the Euphrates and on the left bank of the Tigris must be reckoned to the country "between" the rivers On the other hand, the country between the sources of the Euphrates and the Tigris has from early times been reckoned not to Mesopotamia but to Armenia In this direction the Masius range forms the proper boundary, and it is only on rare occasions that theoretical geographers extend the name Mesopotamia over the more northern districts, Sophene, &c Purely theoretical too, and not to be approved, is the extension of the definition so as to include the land of Babylonia ('Irák 'Arabi), that is, the country as far south as the confluence of the Euphrates and Tigris, or even as far as their embouchure in the Persian Gulf

From what has been said it appears that Mesopotamia reaches its northern limits at the points where the EUPHRATES (*q v*) and the Tigris break through the mountain range and enter the lowlands In the case of the Euphrates this takes place at Sumeisát (Samosata) in that of the Tigris near Jezíret ibn 'Omar (Bezabde) and Mosul (Nineveh) Consequently the irregular northern boundaries are marked by the lowland limits of those spurs of the Taurus mountains known in antiquity as Mons Masius and now as Karaje Dágh and Tur 'Abdin Towards the south the ancient boundary was the so-called Median Wall, which, near Pirux Shapur, not much to the south of Hit (the ancient Is), crossed from the Euphrates in the direction of Kadisiya (Opis) to the Tigris There the two rivers approach each other, to diverge again lower down At the same place begins the network of canals connecting the two rivers which rendered the country of Babylonia one of the richest in the world, there too, in a geological sense, the higher portion of the plain, consisting of strata of gypsum and marl, comes to an end there at one time ran the line of the sea coast, and there begin those alluvial formations with which the mighty rivers in the course of long ages have filled up this depressed area Mesopotamia thus forms a triangle lying in the north west and south east direction, with its long sides towards the north and south west It extends from 37 30 to about 33 N lat and from 38° to 46° E long, and has an area of some [illegible] 200 square miles The points at which the rivers issue from among the mountains have an absolute altitude of between 1000 and 1150 feet and the plain sinks rapidly towards the southern extremity of Mesopotamia, where it is not more than about 165 feet above the sea As a whole the entire country consists of a single open stretch save that in the north there are some branches of the Taurus—the Nimrud Dagh near Orfa, the long limestone range of 'Abd el 'Aziz running north north west, and farther to the east the Sinjar range, also of limestone, 7 miles broad and 50 miles long, running north north east Between these two ranges—near the isolated basaltic hill of Tell Kókab (Hill of Stars)—runs the defile by which the waters of the Chaboras, swollen by the Jaghjagha and other affluents from the Masius, find their way into the heart of Mesopotamia The Khábur proper, the ancient Chaboras, which rises in the three hundred copious fountains of Rás 'ain (the ancient Rhesaina) and ultimately falls into the Euphrates near Karkisiya (Circesium) forms the boundary between the two, or more correctly the three, great divisions of Mesopotamia These divisions are (1) the northern country to the west of the Khábúr, (2) the northern country to the east, and (3) the steppe land In the country to the north west of the Khábur we must probably, as already mentioned, recognize the true ancient *Aram Naharaym* Under the dominion of the Seleucids it bore the name of Osrhoene, or better Orrhoene, and was for a time the seat of a special dynasty which at a later date at any rate was Arabian (Abgar) The capital of this kingdom was Orfa (Roha), the Edessa of the Greeks and Romans, the Orrhoi of the Syrians, it was at a later date a Roman colony, and bore also the name of Justinopolis This once flourishing city lies on the small river Daisan (the ancient Scirtus) South of Edessa lie the ruins of **HARRAN** (see vol xi p 454) In the Mongolian period Harran fell into decay, and at present it is a mere heap of ruins A third town of this region is Serug (Gen xi 20), in the Greek period it was called Batne, but the Syrians retained the name Serug, which is still in use (Seruj) The town lies between Harran and the Euphrates, in a plain to which it gives its name On the left bank of the Euphrates lay Apamea (the modern Birejik), connected with Zeugma on the other side by a bridge, and farther south, at the mouth of the Bilechas (modern Belik), was the trading town and fortress Nicephorium, founded by command of Alexander, and completed by Seleucus Nicator, in memory of whose victory it was named From the emperor Leo it received the designation Leontopolis The spot is now known as Rakka (see below) Farther up the fruitful valley of the Belik lay the town of Ichnæ (Chne) Farther south lay Circesium (*Chaboras* of Ptolemy, *Phaliga* of Isidor), not to be identified, as is usually assumed, with Carchemish from the time of Diocletian it was strongly fortified The site is at present occupied by a wretched place of the name Karkísiya Carchemish probably lay near the bridge of Membij the present Kal'at el Nejm

---

[1] *Μεσοποταμια*, more exactly *η μέση των ποταμῶν*, scil *χωρα* or *Συρία*

[2] In the more recent parts of Genesis Padan Aram takes the place of Aram Naharaym But this perhaps is the name of a smaller district in the neighbourhood of Harran

In ancient times a highly flourishing district must have stretched along the river Chaboras (Khábur) to its principal source at Rás'ain (Fountain head Syr *Rish'aina*, the Rhesæna of Ptolemy), a town which was for some time called Theodosiopolis, because after 380 A D it was extended and embellished by Theodosius Justinian fortified it The strip of completely desert country which now stretches along the lower course of the Khábur was called in antiquity Gauzanitis, and corresponds to the Gozan of 2 Kings xviii 6 (Guzana or Guzanu in the cuneiform inscriptions)

The country to the east of the upper Khábur is in many respects similar to that which has just been described As the watershed of the Tigris is not far distant, the Masius range sends down into Mesopotamia only insignificant streams, the most important being the Hermas, the Mygdonius of the Greeks On its banks was situated Nisibis, the chief city of the district, which commanded the great road at the foot of the mountains leading through the steppe, which here from the scarcity of water comes close up to the edge of the hills In the old Assyrian empire Nasibina was the seat of one of the four great administrative officials In the time of the Seleucids the site was occupied by the flourishing Greek colony of Antiochia Mygdonia, but the new designation, transferred to the river and the vicinity of Nisibis from the Macedonian district of Mygdonia, afterwards passed out of use Nisibis was an important trading city, and played a great part in the wars of the Romans against the Persians Captured by Lucullus surrendered by Tigranes recovered by Trajan, again abandoned by Hadrian, once more occupied under Lucius Verus and strongly fortified by Severus, it was at length raised to be the capital of the province, and remained the frontier fortress of the Romans till in the time of Jovian it was ceded to the Persians After the loss of Nisibis the emperor Anastasius in 507 founded to the north west the fortress of Daræ or Daras (the modern Dárá), also called Anastasiopolis, which from the reign of Justinian, who increased its strength, remained for a time the residence of the *dux Mesopotamiæ* Besides these strongholds, many fortified posts were established by the Byzantine empire in this district Antoninopolis must be mentioned as an important town this was refortified by Constantine under the name of Constantia, and has left its ruins near Tela between Harran and Nisibis Mardin too was a fortress of a similar kind, and the town of Singara at the southern foot of the mountain of the same name, was an advanced post of the Roman power

The south or steppe portion of Mesopotamia was from early times the roaming ground of Arabic tribes, for Xenophon gives the name of Arabia to the district on the left bank of the Euphrates to the west of the Khábúr, and elsewhere it is frequently stated that the interior at a distance from the rivers was a steppe inhabited by Arabes Scenitæ (Tent Arabs) Along the bank of the two great rivers ran a belt of cultivated country, and the rocky islands of the Euphrates were also occupied by a settled population On the Euphrates, beginning towards the north, we must mention first Zaitah or Zautha, south east of Circesium, next Corsothe, at the mouth of the Mascash, then Anatho or Anathan, the modern Ana, and finally Is (Hít) On the Tigris the point of most importance is Carnæ (Καιναί of the *Anabasis*), south from the mouth of the Great Zab near the present Kal'at Sherkát, and not far distant towards the interior was Atræ or Hatræ, also called Hatra, the chief town of the Arab tribe of the Atreni It was besieged without success by Trajan and Severus, by the 4th century it was already destroyed, but the interesting ruins, which can scarcely be visited owing to the plundering habits of the Bedouins, still bear the name of El Hadhr They lie in the heart of the steppe, and were formerly well supplied with water

All these districts came in 640 A D, or perhaps a little earlier, into the power of the Arabs, who named them Jezira (island) or Jezíret Akur,[1] and divided them according to tribes into three portions, the land of Bekr, of Rebí'a, and of Modhar The district of Modhar ran along the side of the Euphrates, and its chief towns were Orfa and Rakka, the district of Rebí'a comprised the plain of Mosul as far as the country on the Khábur (chief towns Mosul and Nisibis), and the district of Bekr (Diyár Bekr) the more mountainous country to the west of the upper Tigris (chief town Amid or Diarbekr) In general the Arabs consider a part of the mountain territories which lie between the two rivers to belong to Jezíra, as is best seen from the following notice given by Abulfeda —

> "El Jezira is the land between the Tigris and the Euphrates, yet many places on the other side of the Euphrates which properly belong to Syria are also included, as well as places and even districts *on the east side of the Tigris* The exact boundary line thus runs from Malatia by Sumeisat, Kal'at er Rum (Rum Kala of the maps) and Bire (Birejik) to the point opposite Membij, and then by Bális Er Rakka, Karkisiya Er Rahaba (on right bank), and Hit to Anbár Here the Euphrates ceases to form the boundary, which runs across to the Tigris in the direction of Tekrit, and ascends the Tigris as far as Es Sinn (Senna) to El Haditha and Mosul thence to Jezíret ibn Omar, then to Diarbekr, and so back to Malatia

From the Arabic geographers and travellers we gain the impression that a great part of Mesopotamia, with the exception of the southern steppe of course, must at that time have been in a very flourishing condition, the neighbourhood of Nisibis especially is celebrated as a very paradise In fact it is only since the Turkish conquest of the country under Sultan Selim in 1515 that it has turned into a desert and gradually lost its fertility As the nomadic Arabs have continually extended their encroachments, agriculture has been forced to withdraw into the mountains, and this is especially true of the western portions of Mesopotamia, the district of Rás'ain, and the plain of Harran and Seruj, where huge mounds give evidence that the whole country was once covered with towns and villages Under the Turks El Jezíra does not form a political unity, but belongs to different pashaliks

From this brief survey it appears that Mesopotamia, like Syria, constitutes an intermediate territory between the great eastern and western monarchies,—Syria inclining more to the west, and Mesopotamia to the east In virtue of its position it frequently formed both the object and the scene of contest between the armies of those mighty monarchies, and it is wonderful how a country so often devastated almost always recovered The roads, it is true, which traversed the territory were not mere military highways, but the main routes of traffic for Central Asia, Western Asia, and Europe It is only in modern times, and since these lines of commercial intercourse have ceased to be followed, that the general condition of things has been so entirely altered

---

[1] Philostratus (c 200 A D) already reports that the Arabs called Mesopotamia νῆσος

The number of roads which in ancient times traversed the country was very considerable, the Euphrates formed not a barrier but a bond between the nations on either side, at many places there were at least boat bridges (zeugma) across One of the most important of the ancient crossing places must be sought, where in fact it still exists, at Birejik, the ancient Apamea Zeugma From this point a great road led across to Edessa (Orfa), there it divided into two branches, the northern going by Amid (Diarbekr) and the other by Mardin and Nisibis to Mosul (Nineveh) In quite recent times, in order to avoid the direct route across the desert and through the midst of the Bedouins, the post road makes a great circuit from Nisibis by Jezíret ibn 'Omar to Mosul A second route crossed the Euphrates somewhat more to the south, and joined the other *via* Harran and Rhesæna The principal crossing of the earlier times (Xenophon) was at Thapsacus, almost opposite Rakka, and it will be remembered also how important a part Thapsacus (Tiphsah) plays in the Old Testament Sometimes a route along the Euphrates to Babylonia was followed, as is still frequently done by caravans at the present day, but even in ancient times this course was attended by more or less difficulty, the country being occupied by the chiefs of independent Arab tribes, with whom the travellers had to come to terms

The ancient condition of things must consequently be considered as essentially analogous to that of the present day, the central districts away from the rivers were occupied at certain seasons, according as they yielded pasture, by nomadic cattle grazing tribes, the physical character of the country being then and now the same on the whole as that of the Syrian desert, which belongs not to Syria but properly to Arabia On the banks of the rivers were settled half nomadic Arab tribes,—tribes, that is, which were more or less on the way to the agricultural stage, or which, having become altogether agricultural, had never theless, owing to frequent intercourse with the Bedouins, lost little of their original character, and even maintained their independence The same movement takes place over and over again Arab tribes migrating from Arabia, that *officina gentium*, gradually settle down wherever circumstances prove favourable, and by this very change in their mode of life make their first step towards civilization In this way a continual stream of Arabs has flowed into the civilized countries of Mesopotamia On the Assyrian monuments are figures of Arabs riding on camels, evidently the Assyrians had carried on war against the Bedouins settled in their territory At an early period the Tai Arabs were the neighbours of the Aramæans, and consequently all Arabs bear in Syriac the name of Tayôyé The district between Mosul and Nisibis received the name Béth 'Arbâyé from its being occupied by Arabs These Tai Arabs, whose original home was Central Arabia, are still settled partly near Nisibis and partly east of Mosul but they have to some extent lost their old noble Bedouin manners The wandering Arab tribe which at the present time is dominant in Mesopotamia is the Shammar, they have driven back the Aneze, the most powerful tribe of the Syrian desert It is only two or three generations ago that the Shammar came from Nejd, but they have already broken up into two great parties The head of the one division is Ferhán, who has more or less completely submitted to the Turks, and has consequently obtained the title of pasha, to him adhere the Shammar tribes between Mosul and Baghdad, and those also to the east of the Tigris The head of the tribes who roam over the greater part of Mesopotamia—pasturing their camels and sheep to the east of the Chaboras in the colder season and to the north in the hotter—is the chivalrous Fáris These western tribes are totally independent of the Turkish Government, and have offered determined opposition to the attempts of the authorities at Dér to force them to a settled way of life, they still lay the peasants of Mesopotamia under contribution by exacting Khuwwe, "brother money, or a portion of grain The Shammar live in almost perpetual feud with their relations to the east, and especially with the Aneze on the Syrian bank of the Euphrates, the so called Shámíye Many other Bedouin tribes might here be mentioned, but it may be enough to name the Delem on the Euphrates as an example of a tribe just in process of becoming agricultural In the northern parts of Mesopotamia there are a number of tribes of mingled Kurds and Arabs which have to a greater or less degree abandoned their tents for fixed habitations and the tillage of the ground, such are the Beraziye near Orfa, the Milliye between Orfa and Mardin, and the Kikiye nearer Mardin and also in the neighbourhood of Mosul It is extremely hard to obtain trustworthy statistical information about the number of the Bedouins, the Shammar may have a total strength of some 3500 tents In the difficult contests which it has to carry on with those independence-loving tribes, the Turkish Government acts in general on the principle *divide et impera*

The Kurdish element only appears sporadically in the true Mesopotamian plain, but the Yezidis, who form the population of the Sinjar range, may be referred to this stock He who encounters the uncanny figure of one of these people will hardly be able to restrain a slight shudder, especially if he remembers the graphic descriptions of the Yezidi robbers in Morier's *Ayesha* Of the old Aramæan peasantry there are no longer any important remains in the plain, the Aramæans having withdrawn farther into the Kurdish highlands, where, in spite of their wild Kurdish neighbours, they are more secure from exactions of every kind The plain of the northern country of the two rivers was at one time richly cultivated, and owed its prosperity to this industrious people, who formerly played so distinguished a part as a connecting link between the Persians and the Roman empire and afterwards between the Western and the Arabian world and whose highest culture was developed in this very region Quite otherwise is it now In the plain there are almost no remains of the common Aramæan tongue Apart from the scattered areas in which Kurdish prevails, the ordinary language is a vulgar Arabic dialect, but both Kurdish and Aramæan (Syriac) have exercised an influence on the speech of the Arab peasant Finally it must be mentioned that certain Turcoman hordes roam about the Mesopotamian territory

In climate and in the character of its soil as well as in its ethnographic history Mesopotamia holds an intermediate position In this aspect also we must maintain the division into two quite distinct zones The southern half consists mainly of grey dreary flats covered with selenite and gypsum everywhere makes its appearance a little below the surface bitumen is not unfrequent and here and there it rises in petroleum wells In the solid strata of gypsum and marl the rivers have carved out valleys from a quarter to half a mile broad and from 40 to 50 or even 100 feet deep which with their arable soil contrast with the barren surface of the more elevated desert (chól) Especially below Balis there are marl hills capped with gypsum, and alluvial plains so called *hawis*) of considerable extent have been formed. The banks of the rivers are there lined with a luxuriant growth of tamarisks. Occasional swamps and small lagoons occur, and the marl shows a more or less marked efflorescence of salt. In this part of the country frost is rare even in winter; in summer the heat is of extraordinary intensity, and during the whole season from May to the close of October it is but slightly modified by the night dews. During the sand storms which frequently blow from the West Arabian desert, the temperature may rise to 50° C. (122° Fahr.), and this same excess of heat will then prevail through seven degrees of latitude in the whole valley of the Euphrates and Tigris from the Persian Gulf to the foot of the mountains. For considering the strong radiation which takes place over what is now the uniform surface of the Mesopotamian soil with its almost complete absence of evaporation there is nothing to hinder this warm zone extending in summer to the upper half of the country. In winter, on the other hand, this latter region has quite a different climate. From the mild coasts of the Mediterranean the cold increases from west to east. In the spurs of the Taurus consequently the winter cold extends far to the south, and the influence of the snow-covered ridges spreads far into the Mesopotamian plain. Snow and ice are thus not unfrequent in the higher part of the plain, and the temperature may fall as low as −10° C. (14° Fahr.), especially if the cold north winds are blowing. That inland region too is cut off from the influence of the mild air of the Mediterranean by the coast ranges. For this reason the vegetation is of a less southern character than that of the Mediterranean countries in the same latitude. In the spring the green is soon parched out of existence. In this way the northern district of Mesopotamia combines strong contrasts, and is a connecting link between the mountain region of western Asia and the desert of Arabia. On the other hand the country to the south of Mesopotamia, or Irak, has a warm climate, and toward the Persian Gulf indeed the heat reaches the greatest extremes.

In Upper Mesopotamia strictly so called, agriculture has suffered an extraordinary decline; in spite of excellent soil very little of the land is turned to account. In the western district the fertile red-brown humus of the Orfa plain, derived from the lime of Nimrud Dagh, extends to about 12 miles south of Harran. With a greater rainfall and an artificial distribution of the water such as existed in olden times, agriculture would flourish. If spring rains are only moderately abundant, wheat and barley grow to a great height and yield from thirty to forty-fold. Rice is also grown in the richly watered hill-encircled district of Seruj and on the banks of the Khabur. Next millet and sesamum are the chief crops—the latter being grown for the sake of its oil, as the olive does not succeed in this region. The abundance of wheat may be estimated from the fact that during Layard's residence in Mosul a camel-load of 480 lb was worth four shillings. Durra (*Holcus Sorghum* and *H. bicolor*), lentils, pease, beans and vetches are also grown, as well as cotton, safflower, hemp and tobacco. *Medicago sativa* furnishes fodder for horses. Among the fruits the most noteworthy are the cucumbers, melons and water-melons planted in great abundance on the banks of the smaller streams. The figs of the Sinjar mountains are celebrated for their exceptional sweetness. Timber trees are few; plane trees and white poplars are planted along the streams, and a kind of willow and a sumach flourish on the banks of the Euphrates. The palm trees which appear on the banks of both the rivers further south do not come so far north. On account of the hot dry summer the orange does not succeed. Of the great forest which existed (?) near Nisibis in the time of Trajan no trace remains; but the slopes both of the Masius mountains and of the Jebel Abd el Aziz, as well as, more especially, those of the Sinjar range, are still covered with wood.

The wide treeless tracts of the low country of Mesopotamia are covered with the same steppe vegetation which prevails from Central Asia to Algeria, but there is an absence of a great many of the arborescent plants that grow in the rockier and more irregular plateaus of western Asia and especially of Persia. This comparative poverty and monotony of the flora is partly due to the surface being mainly composed of detritus, and partly to the cultivation of the country in remote antiquity having ousted the original vegetation and left behind it what is really only fallow ground untouched for thousands of years. Endless masses of tall weeds belonging to a few species cover the face of the country—large *Cruciferæ*, *Cynareæ* and *Umbelliferæ* disputing the possession of the soil in company with extraordinary quantities of liquorice (*Glycyrrhiza glabra* and *echinata*) as well as *Lagonychium* and the white ears of the *Imperata*. In autumn the withered weeds are torn up by the wind and driven immense distances. Among the aromatic plants which even Xenophon mentions in Mesopotamia the first place belongs to the species of wormwood (*Artemisia*), which cover wide areas, and the second to *Labiatæ*, such as species of thyme and *Salvia*, which, however, become rarer in the low country. With few exceptions there are none but cultivated trees, and these are confined to the irrigated districts on the Euphrates and the Shatt; a few willows, a *Pyrus*, tamarisks, a *Rhus*, a *Rubus*, on the banks of the rivers, and the willow-like *Populus euphratica*, which grows from Dzungaria to Morocco, make up the list of the indigenous kinds. In the wide belt of swamp which lines the Shatt el Arab in the low country of Irak Arabi there are boundless reaches of gigantic sedge inhabited by a rich fauna, especially of birds such as pelicans and flamingoes. From the south, or in other words from the true desert and oasis country of Arabia, the date palm spreads up the valley to some little distance above Baghdad, and especially along the Shatt it yields rich crops of fruit, which are exported to India. With the exception of a few truffles, capers, liquorice and such like, there are few wild food plants. The cycle of vegetation begins in November. The first winter rains clothe the plain with verdure, and by the beginning of the year a number of bulbous plants are in bloom—*Amaryllidæ*, *Liliaceæ*, and *Colchicum*. The full summer development is reached in June, and by the end of August everything is burnt up.

The lion is said to roam as far as the Khabur, but in any case it is at least much less frequent than in the time of the Assyrians, when the lion hunt was a recognized form of sport. The wild ass too is very rare, but on the other hand wild swine, hyænas, jackals, cheetahs, and foxes are extremely abundant. Wolves are said to exist in the plain, and among others a variety of black wolf (*Canis lycaon*). Particularly numerous in the steppe are the antelope species, and herds of gazelles are frequently met with. Beavers are said to have been observed on the Euphrates. Jerboas, moles, porcupines and especially the common European rat abound in the desert, bats are numerous, and the long-haired desert hare is also found. Among the domestic animals in this steppe country the camel holds the first place, and next come goats and sheep, but the Bedouin sheep is not the ordinary fat-tailed variety. The common buffalo is often kept by the Arabs and Turcomans on the Euphrates and the Tigris, and on the Euphrates we also find the Indian zebu, which is still more frequent in the districts farther to the south. Bird life is very rare in the southern parts of the plain, though on the Euphrates there are vultures, owls, ravens, &c., as well as falcons (? *Tinnunculus alaudarius*) which are trained to hunt. Among game birds are some kinds of doves, francolins, partridges, wild ducks and geese, and in the steppe bustards. The ostrich seems almost to have disappeared. Large tortoises are numerous.

In conclusion it is necessary in supplement to the article IRAK to say something of the district of Babylonia often (though wrongly) included under the name Mesopotamia. Here we have to do with a fundamentally different region, for it consists in the main of alluvial formations, a few scattered reaches of sand only now and then appearing in the level depression not filled up by the alluvium. The mass of solid matter which the rivers bring down and deposit is very considerable; it has been ascertained that the maximum proportion for the Euphrates in the month of January is $\frac{1}{80}$, and at other times $\frac{1}{700}$; for the Tigris the maximum is $\frac{1}{100}$. As regards the physical character of the alluvium, in the most northerly portion the soil is pebbly, the pebbles consisting almost solely of variously coloured flints and occasional small fragments of gypsum. This is succeeded by a continuous formation of clayey soil, in part argillaceous and argillo-calcareous, but covered with mould and sand, or the more tenacious clay of frequent inundations.

In general the northern plains of the interior have a slight but well defined southerly inclination with local depressions. The territory undulates in the central districts, and then sinks away into mere marshes and lakes. The clay, of a deep blue colour, abounds with marine shells, and shows a strong efflorescence of natron and sea-salt, the latter derived from the decomposition of vegetable matter. When the soil is parched up the appearance of the mirage (serab) is very common. As extensive inundations in spring are caused by both the rivers, especially the Tigris, great alterations must have taken place in this part of the country in the course of thousands of years. It has been asserted that in former times the alluvial area at the mouth of the river increased one mile in the space of thirty years, and from this it has been assumed that about the 6th century B.C. the Persian Gulf must have stretched from 45 to 55 miles further inland than at present. The actual rate of increase at the present time is about 72 feet per annum. For this reason we cannot decide much in regard to the former physical configuration of southern Babylonia, but it is at least certain that the Euphrates and the Tigris reached the sea as independent rivers. Ritter estimates that in the time of Alexander the Great the embouchures were still separated by a good day's journey, and, though they cannot now be traced, great alterations have probably taken place in the upper portions of the rivers as well as in the country near the mouths. Assyriologists tell us that more than thirty-five canals are known by name from the Babylonian period, but it is extremely difficult, or rather it has proved hitherto impossible, to identify them either with those actually existing or with those mentioned in classical authors, in the Babylonian Talmud, or in Arabian writers. To the west of the Euphrates was to be found the Pallacopas channel, and we still have the Hindiye channel in the same quarter. The country between the rivers more particularly was traversed by such secondary branches. Beginning from the Euphrates we must mention the Saklawiye channel (Nahr 'Isá), the Nahr Melik, the Nahr Zemberaniye, and especially the Nahr en Nil, constructed by the famous Omayyad governor Hajjáj. Eastwards from the Tigris strikes the great Nahrawan channel; and right through the country of the two rivers runs the Shatt el Hai from Kût el Amara almost due south to the Euphrates, parallel with the Shatt el Kehr. Many of these have been silted up; from those, however, which are still maintained there is derived a considerable revenue; and by the restoration of many of the old channels, traces of which are met with at every step, the country might be again raised to that condition of high civilization which it enjoyed not only in antiquity but partly even in the time of the later caliphs. The classical writers are unanimous in their admiration of this country; and it is at least certain that nowhere else in the whole world was the principle of the application of canals to the exigencies of agriculture worked out so successfully. The most luxuriant vegetation was diffused over the whole country; and three crops were obtainable in the year. It is this alone which makes it intelligible how this region in the most remote antiquity attained a high civilization, and for centuries played, it may be said, one of the principal parts in the history of the world. In the matter of civilization, indeed, no country of the ancient world was its equal; a multitude of great cities once flourished within its borders. Even the Arabic writers are unanimous in regard to the extremely favourable influence which the character of the country exercised on the intellectual activity, spirit and capacity of its inhabitants. We need not here discuss the question recently started as to whether the Biblical garden of Eden is to be sought in this locality, two canals of the Euphrates and Tigris being identified with the Gihon and Pison of Gen. ii.; but it is certain at least that this lower country of the two rivers might well pass in antiquity for the *ne plus ultra* of civilization, and exercised the most powerful political and intellectual influence on the surrounding regions. The question often raised as to whether the Semites were derived from this district may also be left untouched. From the Bible we know that an ancient name of the district was Shinar, though this has not hitherto been discovered in the cuneiform inscriptions. The name Kush is applied in the Bible to its oldest non-Semitic inhabitants. The northern half of the country was called Akkad, the southern Sumer. But it must not be forgotten that the rivers never formed ethnographic and political boundaries; and thus Sumer extended to the coast of the Persian Gulf and Akkad as far as the Lower Zab, the eastern affluent of the Tigris. As a less ancient designation of the whole country may be reckoned *mat Kalda*, the country of the Chaldæans (Hebr., *erets Kasdim*); originally Kalda is said to have designated central Babylonia. Of still later date is the name derived from the capital, the country of Babel (*erets Babel*), as an equivalent of which *mat Bâbîlû* appears in the cuneiform inscriptions (in the Darius lists *Babiru*). From this was developed the Greek designation Babylonia, Βαβυλωνία (as early as Xenophon). That the country was densely peopled may be gathered from the fact that about 704 B.C. eighty-nine fortified towns and eight hundred and twenty smaller places in the Chaldæan country were captured during one military expedition. Of separate districts of the country we may mention Karduniash, the district in the vicinity and especially to the north of Babylon; and southward by the sea-coast the important country of Bit Yakin, governed by kings of its own. At a later date we find on the coast and at the mouth of the Pallacopas canal the maritime town of Teredon, which is also mentioned by the classical writers. Besides Babylon and Borsippa, the larger cities were the double city of Sippar (Sefarvayim, 2 Kings xvii. 24, 31) and Akkad on the left bank of the Euphrates on the present Nahr Isa; Erech, *i.e.*, Warka, on the left bank of the Euphrates; Ur on the Pallacopas, not far from the place where the Shatt el Hai falls into the Tigris; Nippur, *i.e.*, Tell Niffer; Kutha (2 Kings xvii. 24); Kalne (Gen. x. 10), in the north, Opis at the junction of the Adhem (Physcus) with the Tigris. Huge mounds give evidence of the extent of these cities. A number of the canals were navigable, and at the same time, when the bridges were destroyed, they formed defensive moats against the incursion of enemies from the north. And the same purpose was served by the great wall (afterwards the Median Wall of the Greeks) which ran across the country from river to river between the points of their nearest approach.

During the period of Greek domination a Greek city, Seleucia, which afterwards attained great prosperity, was founded by Seleucus I. in an extremely favourable situation on the right bank of the Tigris. In the south of the country, too, there was a Greek seaport town, first called Alexandria on the Tigris and afterwards Antiochia. After the conquest of Babylonia by the Parthians (130 B.C.) a small Arabian kingdom grew up in those parts called Characene or Mesene, after the town of Charax or Maisan. It was under Parthian and for a time under Roman supremacy. The city of Vologesia, founded by Vologeses to the south-west of Babylon, near Ullais, in the neighbourhood of the later Kufa, was one of the capitals of the Parthian power. In the time of the Sasanids, too, as well as in that of the Parthians, the country of the lower Euphrates and Tigris played a leading part; it formed in fact the main centre of the Persian kingdom. The city of Ctesiphon, founded by the Greeks on the east side of the Tigris opposite Seleucia, was the winter residence of the Parthian kings, and the imperial capital of the Sasanids. Under the name of Madain (The Cities) it continued to flourish till the rise of Baghdad in the 9th century. The neighbourhood of Ctesiphon was called in the time of the Sasanids Suristan, a translation of the Aramæan designation Bêth Aramaye, 'country of the Syrians,' for the land was mainly occupied by Aramæans. By a notable substitution the Arabs afterwards gave the name Nabat, *i.e.*, Nabatæans, to these Aramæan peasantry, who, it may be added, were already found in these parts at the time of the Babylonian empire.

On the west side of the Tigris the Arab kingdom of Hira formed the bulwark of the Sasanid power. As the result mainly of the battle of Kadisiya (east of Hira) in 635 A.D., the whole of this wealthy country fell into the hands of the Moslems, and it soon constituted the centre of their power, especially when the Abbasids, with true political insight, transferred thither the capital of the empire and founded Baghdad. The chief cities of the older Arabic period were Kufa (in the neighbourhood of the earlier Hira to the south of ancient Babylon) and Basra (or BUSSORAH, *q.v.*) in the neighbourhood of the earlier Maisan. After these two cities the country was divided into the Sawad, "rich arable district," of Basra and that of Kufa. Sawad was also employed as a name for the whole country; and more or less identical with this designation is the name Irak still in use. Sometimes also the term Sawad el Irak is employed; but at a later date the country is distinguished as Irak Arabi (Arabian Irak) from the Persian 'Irak Ajemi to the east, the ancient Media. The Arabian geographer Yakut makes the distinction that the country called Sawad reaches farther to the north (*viz.*, to the district of the Upper Zab).

Abulfeda gives the boundaries of 'Irak as follows:—"In the west of the country lie El Jezira and the desert, in the south the desert, the Persian Gulf, and Khuzistan, in the east the mountain country as far as Holwan (near the principal pass through the Zagros range). Thence the boundary runs again towards Mesopotamia." Thus the greatest breadth of Irak is in the north, and its narrow extremity is formed by the island Abbadan in the Shatt el Arab (the united Euphrates and Tigris) to the south of Basra. From what has been said it appears that Irak extended far beyond the country between Euphrates and Tigris. Abulfeda says clearly that Irak lies on the Tigris as Egypt on the Nile; for according to this view the Tigris flows through the middle of the country. Irak consequently lies between 30° and 34° 30′ N. lat. and between 44° and 48° 30′ E. long.; of its area it is impossible to form an estimate under such varying conditions. For some details see BAGHDAD.

From the union of the rivers upwards, in the case of the Euphrates as far as 36° N. lat. (above Rakka), in that of the Tigris to 35° N. lat., the valleys are known as *el Ġôr*, the depression, in opposition to the more elevated desert plateau. It has been surmised that in this name is to be recognized the Dura of the Old Testament (Daniel iii. 1).

Very little of the ancient condition of the country has been preserved, and there are now but few remains of ancient buildings, scarcity of stone having all along led to the use of bricks. Irak has played its part. It is only by the expenditure of immense sums, far beyond the financial capacity of the Turkish Government, that the ancient canals could be restored and the swamps formed by them drained. The whole land falls into two unequal portions—an extensive dry steppe with at any rate a healthy desert climate, and an unhealthy region of swamps. There is a good deal more agriculture along the Euphrates than along the Tigris; but swamps, with almost impenetrable reed thickets composed of a kind of *Agrostis*, are at the same time much more extensive. The slightly more elevated districts are the special habitat of the date palm, which by itself forms dense groves bordering the banks particularly on the lower Euphrates, for a distance of several days journey. This part of the country consequently has a somewhat monotonous but in its own way imposing aspect. A luxuriant vegetation of water plants is to be found in the swamps, which are the haunt of numerous wild beasts—wild swine, lions, different kinds of aquatic animals and birds. The swamps are inhabited by a wild race of men, dark of hue, with many negroes amongst them. They live in reed huts, and cultivate rice, and they weave straw mats. In the main they keep pretty free both of the Turkish Government and of the semi-Bedouins and Bedouins of 'Irak. The Khazael especially, who dwell to the south of ancient Babylon, often give the Government trouble, through their passion for independence. Less turbulent are the Bedouins in the interior of the country—the Zobeid, the Afaj, and the Abu Muhammed; but on the other hand the Beni Lam (7500 tents strong), who occupy the great tract of country east of the Tigris to the south of Baghdad, have often been a source of great annoyance to the pashas of that city. A still more difficult task is the management of the Shammar, who come and pitch their tents to the south-east of Baghdad, and also the Muntefik on the southern Euphrates put the whole ad ministrative and diplomatic skill of the Turkish officials to the test The Turkish influence has here made at one time great advance and at another lost all the ground it had gained,—the rich and powerful sheikhs of the Muntefitch sometimes becoming for a season rulers over the whole of Southern Irak and even over the town of Basra The present writer once visited the great sheikh Nasir in his camp near Suk esh Shiyukh, and he received the impression of having to do with a very remarkable and astute personage

The old Syrian population of Irak has almost entirely disappeared, the few remnants left are distinguished by a special *religion in regard* to which see the article MANDÆANS Ethnographically the country is subject to a double influence On the one hand the connexion with Nejd, the central plateau of Arabia, continues uninterrupted the emigration from that region being mainly directed towards Irak and Jezira In Baghdad even the Ageil Bedouins from Central Arabia have a quarter of their own With the earnings obtained in these rich districts the emigrants return to their homes But quite as strong at least is the influence of Persia Persian customs are in fashion in Baghdad there is an important Persian quarter and Kerbela and Meshed 'Ali to the west of the Euphrates may be considered regular Persian ' enclaves In these places are buried the son in law of Mohammed the caliph Ali and his son Hosein (in Kerbela) the chief saints of the Shiite sect and their tombs are not only shrines of pilgrimage to the living but the dead are brought by countless caravans from Persia to be buried in ground which they have made holy The neighbourhood of Kerbela reeks with the odour of corpses and from the midst of them pestilence has often begun its march Throughout the whole of Irak the Shiites have many adherents,—for example the Khazael already mentioned Persian influence prevails on the Arab population of Irak and the intermingling of the races can still be very clearly traced, in this distant corner of the Turkish empire a more international tone prevails than in any other district And however small when compared with former times the commercial and intellectual intercourse of various nations in these regions may be at the present day, the attentive observer must notice that such intercourse does still exist though within restricted limits No trace, indeed is to be found of that rich intellectual development which was produced in the time of the caliphs through the reciprocal action of Persian and Arabic elements Still the quickwittedness of the inhabitants of Irak makes a decided impression on the traveller passing through Asiatic Turkey and one might venture to prophesy that the country might to some extent recover its former position in the world, especially if English influence from India were more widely extended, and should lead to the construction of a railway The trade which passes through Irak is even now not unimportant, horses for example are exported in considerable numbers from southern Irak to India But it might be very much improved as the country, it is said, could support five hundred times as many inhabitants as it actually contains There is also a considerable export of dates a fruit which forms the chief sustenance of a great number of the inhabitants and the breeding of cattle (especially buffaloes) is extensively carried on Only a few steamboats as yet navigate the majestic rivers Communication by water is carried on by means of the most primitive craft Goods are transported in the so called "terrades moderately big high built vessels which also venture out into the Persian Gulf as far as Kuwet Passengers are conveyed especially on the Euphrates, in the *meshhûf*, a very long and narrow boat mostly pushed along the river bank with poles The Mesopotamian "kelleks —rafts laid on goatskin bladders—come down as far as Baghdad where round boats made of plaited reeds pitched with asphalt are in use At Basra, on the other hand, we see the ' belem, boats of a large size, having the appearance of being hollowed out of tree trunks and partly in fact so constructed Throughout Irak in general Indian influence is partially at work, in the hot summer months for instance, when the natives live in underground apartments (serdab), the Indian punkah is used in the houses of the rich As regards language, the local Arabic dialect has evidently been affected on the one hand by Persian, on the other by the Bedouin forms of speech

See Ritter *Die Erdkunde von Asien* 2d ed vol vii 10th and 11th parts Berlin 1843 1844 Chesney *Expedition for the Survey of the Rivers Euphrates and Tigris* 2 vols London 1850 W Ainsworth *Researches in Assyria Babylonia and Chaldæa* London 1838 Fr Delitzsch *Wo lag das Paradies?* Leipsic 1881 Map Kiepert *Die Euphrat und Tigrisländer* Berlin 18 4 (A SO)

MESSENE, the chief city of Messenia, founded, under the auspices of Epaminondas, as a bulwark against the Spartans After the battle of Leuctra that general sent to all the exiled Messenians,—in Africa, Sicily, or Italy,—and invited them to return to the land of their fathers Many came with eagerness, and in 369 B C the city was built by the combined army of Thebans under Epaminondas and Argives under Epiteles, assisted by the Messenians themselves The site was chosen in conformity with a vision which appeared to Epaminondas, and the walls were raised to the sound of flutes playing the airs of Sacadas and Pronomus The citadel was erected on the summit of Mount Ithome, and the city on its southern slope and in the adjoining valley City and citadel were enclosed by a wall 47 stadia in length Near the centre of the city was the agora, with a famous spring called Arsinoe, and various temples and statues, among the latter an iron statue of Epaminondas The Hierothysion contained many statues of gods and heroes, among them a bronze statue of Epaminondas In the gymnasium were statues of Hermes, Hercules, and Theseus by Egyptian artists In the stadium was a bronze statue of the great hero Aristomenes, who had a sepulchral monument elsewhere in the city On the summit of the citadel was a famous spring called Clepsydra, and near it a temple of Zeus Ithomatas, with a statue by the famous Argive artist Ageladas, executed originally for the Messenian Helots who settled in Naupactus (see MESSENIA) It was in honour of this statue that the festival of the Ithomæa was performed

The situation of Messene is one of the finest and most romantic in the world The view of Mount Ithome, with its level summit and its ancient and mediæval ruins, as one issues from the Langadha Pass in the Taygetus mountains, is beautiful beyond description And the view from the summit of the mountain itself, which rises, steep and rugged, to the height of 2631 feet, and is crowned by the ruins of fortifications of Cyclopean workmanship, is enchanting, hardly equalled by any other in Greece Near the middle of the ruins of the lower city stands a wretched village named Mavrommati (Black Eye), so called from the Turkish name of the spring Arsinoe, which still flows as plentifully as in the old days These ruins are the most imposing in Greece, and furnish the finest existing specimen of Hellenic military architecture Almost the entire circuit of the ancient walls can be traced, and in some places they are standing to their full height They are built of large hewn stones laid in beautifully regular layers without mortar, and are surmounted by towers, of which there seem to have been originally over thirty Seven of these are still in a good state of preservation, and bear testimony to the thoroughness of the great enterprise undertaken by Epaminondas Two gates can still be distinguished, one on the slope of Mount Ithome, the other (the northern or Megalopolis gate) on the north side The latter is a dipylon or double gate, opening into a circular enclosure 62 feet in diameter The walls of this enclosure are built with extreme care, and the soffit stone of the inner portal, which has been partly moved from its place, reminds one of the lintel of the so-called treasury of Atreus at Mycenæ It is 18 ft 8 in × 4 ft 2 in × 2 ft 10 in Within the town several ancient sites can still be distinguished—the stadium, the theatre, and several temples

MESSENIA (in Homer Messene), a state of Greece, and the most westerly of the three peninsulas of the Peloponnesus Its area is a little over 1160 square miles It is separated from Elis and Arcadia on the north by the river Neda and the Nomian mountains, and from Laconia on the east by the lofty range of Taygetus The other sides are washed by the sea, which indents its shores with four gulfs or bays,—Messenia, Phœnicus, Pylus, and Cyparissus On its south west corner are the Œnussæ Islands, and opposite the bay of Pylus (Navarino) the famous Sphacteria. The interior is divided by mountain chains into fertile plains, watered by rivers, the chief of which is the Pamisus (with its tributaries Leucasia, Charadrus, Amphitus, and Aris), falling into the Messenian Gulf. The great valley of this river is divided, near Mount Ithome, into two distinct parts, the plain or basin of Stenyclarus on the north, and the plain of Macaria, so called from its extreme fertility, on the south. The climate is delightful.

The earliest inhabitants of Messenia were Leleges, whose capital was at Andania. After these came Ætolians, whose chief centre was at Pylus. After the Dorian conquest the country was divided by Cresphontes into five parts, whose chief cities were respectively Stenyclarus, Pylus, Rhion, Hyamia, and Mesola. The towns of Messenia were not numerous. Homer mentions Pylus (the seat of the Thessalian Neleids), Amphigeneia (possibly the same as Ampheia), Dorion, Æpeia (possibly Methone), Œchalia, Pharæ, Antheia (probably the later Thuria), Pedasus, and Ira (the later Abia). Other important towns were Asine, Corone, Limnæ, Carnasium, Cyparissia, and, finally, Messene.

Of the history of Messenia before the Dorian invasion little is known except a few fables related by Pausanias. Two generations after the Trojan war, the country was invaded by the Dorians who expelled the Neleids and conferred the sovereignty upon Cresphontes who seems to have been a popular king. Perhaps for this reason he was put to death by the chiefs along with all his sons except Æpytus. Æpytus was restored to the throne by the Arcadians took vengeance for his father's death and became very popular. His line lasted through several generations. We know little of the subsequent history of Messenia until the date of the Messenian wars, waged against Sparta. The ostensible and immediate causes of these wars are variously assigned but the true cause was the cupidity of Sparta. Our chief trustworthy authority for the history of them is the old elegiac poet Tyrtæus, but so little is known about them that it is a matter of doubt in which of them the great hero Aristomenes won his fame. The date of the first was from 743 to 724, of the second from 685 to 668 or according to others from 648 to 631 B.C. Ithome was the centre of action in the first, Eira in the second. The result of these wars was the complete subjugation of Messenia to Sparta. Its territory was parcelled out among Spartans, and its towns handed over to Periœci and Helots. Many of the inhabitants took refuge in Arcadia, but still more in Italy and Sicily. A very large number settled in Rhegium whose chiefs for many generations were of Messenian stock. About 200,000 remained behind in bondage. After the second war a large number of Messenians settled on the Sicilian coast at Zancle, to which they subsequently gave the name Messana (see MESSINA). In 464 B.C. the Messenian Helots taking advantage of an earthquake at Sparta, revolted, and though they were finally compelled to surrender in 455, they did so only on condition of being allowed to retire to Naupactus on the Corinthian Gulf. This city had been offered them as a residence by the Athenians ever glad to favour the foes of Sparta. Here the Messenians remained for sixty years until the loss of the battle of Ægospotami deprived them of the protection of the Athenians. They were then driven out and had to find homes in Cephallenia and Zacynthus, or among their kinsmen in Rhegium and Messana. Some even went to Africa, and took up their abode at Euesperidæ or Hesperidæ, afterwards called Berenice. Things remained in this condition until 369 B.C., when Epaminondas, having broken the power of Sparta rent from her Messenia and, collecting from all quarters the descendants of the exiled inhabitants, helped them to found the city of MESSENE (q.v.). Sparta never gave up her claim to Messenia, and made many attempts to reconquer it, but without success. The Messenians maintained their independence until 146 B.C., when, with the Achaans they were reduced under the power of Rome. From that time they fall into the background of history. In the Middle Ages the country, like the rest of the Peloponnesus, was largely overrun by Slavic tribes, as is shown by the numerous Slavic local names occurring in it. At the establishment of Greece as a kingdom, Messenia was constituted into a province with a governor or nomarch residing at Kalamata (officially Kalamai) the ancient Pharæ. The country, though beautiful and fertile is still in a deplorably backward condition, and the population is sparse and semi-barbarous. Agriculture languishes, and the roads and bridges are few and bad. More deeds of violence occur in Messenia than in any other part of Greece. With the exception of Kalamata, it contains no town of importance. Navarino, on the Gulf of Pylus, was the scene of the destruction of the Turkish fleet in 1827.

MESSIAH (Dan. ix. 25, 26), MESSIAS (John i. 41, iv. 25), are transcriptions (the first form modified by reference to the etymology) of the Greek Μεσσίας (Μεσίας, Μεσσείας), which in turn represents the Aramaic מְשִׁיחָא (*mĕshîḥâ*), answering to the Hebrew הַמָּשִׁיחַ, "the anointed."[1] The Hebrew word with the article prefixed occurs in the Old Testament only in the phrase 'the anointed priest' (Lev. iv. 3, 5, 16, vi. 22 [15]), but "Jehovah's anointed" is a common title of the king of Israel, applied in the historical books to Saul and David, in Lam. iv. 20 to Zedekiah, and in Isa. xlv. 1 extended to Cyrus. In the Psalms corresponding phrases (My, Thy, His anointed)[2] occur nine times, to which may be added the lyrical passages 1 Sam. ii. 10, Hab. iii. 13. In the intention of the writers of these hymns there can generally be no doubt that it refers to the king then on the throne, or, in hymns of more general and timeless character, to the Davidic king as such (without personal reference to one king),[3] but in the Psalms the ideal aspect of the kingship, its religious importance as the expression and organ of Jehovah's sovereignty, is prominent. When the Psalter became a liturgical book the historical kingship had gone by, and the idea alone remained, no longer as the interpretation of a present political fact, but as part of Israel's religious inheritance. It was impossible, however, to think that a true idea had become obsolete merely because it found no expression on earth for the time being; Israel looked again for an anointed king to whom the words of the sacred hymns should apply with a force never realized in the imperfect kingship of the past. Thus the psalms, especially such psalms as the second, were necessarily viewed as prophetic, and meantime, in accordance with the common Hebrew representation of ideal things as existing in heaven, the true king remains hidden with God. The steps by which this result was reached must, however, be considered in detail.

The hope of the advent of an ideal king was only one feature of that larger hope of the salvation of Israel from all evils, the realization of perfect reconciliation with Jehovah, and the felicity of the righteous in Him, in a new order of things free from the assaults of hostile nations and the troubling of the wicked within the Hebrew community, which was constantly held forth by all the prophets, from the time when the great seers of the 8th century B.C. first proclaimed that the true conception of Jehovah's relation to His people was altogether different from what was realized, or even aimed at, by the recognized civil and religious leaders of the two Hebrew kingdoms, and that it could become a practical reality only through a great deliverance following a sifting judgment of the most terrible kind. The idea of a judgment so severe as to render possible an entire breach with the guilty past, and of a subsequent complete realization of Jehovah's kingship in a regenerate nation, is common to all the prophets, but is expressed in a great variety of forms and images conditioned by the present situation and needs of Israel at the time when each prophet spoke. As a rule the prophets directly connect the final restoration with the removal of the sins of their own age, and with the accomplishment of such a work of judgment as lies within their own horizon; to Isaiah the last troubles are those of Assyrian invasion, to Jeremiah the restoration follows on the exile to Babylon, Daniel connects the future glory with the overthrow of the Greek monarchy. The details of the prophetic pictures show a corresponding variation, but all agree in giving the central place to the realization of a real effective kingship of Jehovah; in fact the conception of the religious subject as the nation of Israel, with a national organization under Jehovah as king, is common to the whole Old Testament, and forms the bond that connects prophecy proper with the so-called Messianic psalms and similar passages which theologians call typical, *i e*, with such passages as speak of the religious relations of the Hebrew commonwealth, the religious meaning of national institutions, and so necessarily contain ideal elements reaching beyond the empirical present All such passages are frequently called Messianic, but the term is more properly reserved as the specific designation of one particular branch of the Hebrew hope of salvation, which, becoming prominent in post canonical Judaism, used the name of the Messiah as a technical term (which it never is in the Old Testament), and exercised a great influence on New Testament thought, —the term "the Christ (ὁ χριστος) being itself nothing more than the translation of "the Messiah '

---

[1] The transcription is as in Γεσσουρ, Γεσσιρ for גשור, *Onomastica*, ed. Lag., pp. 247, 281, Βασ. β ii. 3. For the termination ας for חא, see Lagarde, *Psalt. Memph.*, p. vii.

[2] The plural is found in Psalm cv. 15, of the patriarchs as consecrated persons.

[3] In Ps. lxxxiv. 9 [10] it is disputed whether the anointed one is the king, the priest, or the nation as a whole. The second view is perhaps the best.

In the period of the Hebrew monarchy the thought that Jehovah is the divine king of Israel was associated with the conception that the human king reigns by right only if he reigns by commission or "unction" from Him Such was the theory of the kingship in Ephraim as well as in Judah (Deut xxxiii , 2 Kings ix 6), till in the decadence of the northern state Amos (ix 11) foretold the redintegration of the Davidic kingdom, and Hosea (iii 5, viii 4) expressly associated a similar prediction with the condemnation of the kingship of Ephraim as illegitimate So the great Judæan prophets of the 8th century connect the salvation of Israel with the rise of a Davidic king, full of Jehovah s Spirit, in whom all the energies of Jehovah s transcendental kingship are as it were incarnate (Isa ix 6 *sq* , xi 1 *sq* , Micah v) This conception, however, is not one of the constant elements of prophecy, indeed the later prophecies of Isaiah take a different shape, looking for the decisive interposition of Jehovah in the crisis of history without the instrumentality of a kingly deliverer Jeremiah again speaks of the future David or righteous sprout of David s stem (xxiii 5 *sq* xxx 9) and Ezekiel uses similar language (xxxiv, xxxvii), but that such passages do not necessarily mean more than that the Davidic dynasty shall be continued in the time of restoration under a series of worthy princes seems clear from the way in which Ezekiel speaks of the prince in chaps xlv , xlvi As yet we have no fixed doctrine of a personal Messiah, but only material from which such a doctrine might by and by be drawn The religious view of the kingship is still essentially the same as in 2 Sam vii , where the endless duration of the Davidic dynasty is set forth as part of Jehovah s plan of grace to His nation

There are other parts of the Old Testament—notably 1 Sam viii , xii —in which the very existence of a human kingship is represented as a departure from the ideal of a perfect theocracy And so, in and after the exile, when the monarchy had come to an end, we find pictures of the latter days in which its restoration has no place Such is the great prophecy of Isa xl -lxvi , in which Cyrus is the anointed of Jehovah, and the grace promised to David is transferred to ideal Israel ("the servant of Jehovah) as a whole (Isa lv 3) So too there is no allusion to a human kingship in Joel or in Malachi the old forms of the Hebrew state were broken, and religious hopes expressed themselves in other shapes[1] In the book of Daniel it is collective Israel that appears under the symbol of a "son of man," and receives the kingdom (vii 13, 18, 22, 27)

Meantime, however, the decay and ultimate silence of the living prophetic word concurred with the prolonged political servitude of the nation to produce a most important change in the type of the Hebrew religion. The prophets had never sought to add to the religious unity of their teaching unity in the pictorial form in which from time to time they depicted the final judgment and future glory For this there was a religious reason. To them the kingship of Jehovah was not a mere ideal, but an actual reality Its full manifestation indeed, to the eye of sense and to the unbelieving world, lay in the future, but true faith found a present stay in the sovereignty of Jehovah, daily exhibited in providence and interpreted to each generation by the voice of the prophets. And, while Jehovah s kingship was a living and present fact, it refused to be formulated in fixed invariable shape But when the prophets ceased and their place was taken by the scribes, the interpreters of the written word, when at the same time the yoke of foreign oppressors rested continually on the land, Israel no longer felt itself a living nation, and Jehovah's kingship, which presupposed a living nation, found not even the most inadequate expression in daily political life Jehovah was still the lawgiver of Israel, but His law was written in a book, and He was not present to administer it He was still the hope of Israel, but the hope was all dissevered from the present, it too was to be read in books, and these were interpreted of a future which was no longer, as it had been to the prophets, the ideal development of forces already at work in Israel, but wholly new and supernatural The present was a blank, in which religious duty was summed up in patient obedience to the law and penitent submission to the Divine chastisements, the living realities of divine grace were but memories of the past, or visions of "the world to come ' The scribes, who in this period took the place of the prophets as the leaders of religious thought, were mainly busied with the law, but no religion can subsist on mere law and the systematization of the prophetic hopes, and of those more ideal parts of the other sacred literature which, because ideal and dissevered from the present, were now set on one line with the prophecies, went on side by side with the systematization of the law, by means of a harmonistic exegesis, which sought to gather up every prophetic image in one grand panorama of the issues of Israel s and the world s history The beginnings of this process can probably be traced within the canon itself, in the book of Joel and the last chapters of Zechariah,[2] and, if this be so, we see from Zech ix that the picture of the ideal king early claimed a place in such constructions The full development of the method belongs, however, to the post canonical literature, and was naturally much less regular and rapid than the growth of the legal traditions of the scribes The attempt to form a schematic eschatology left so much room for the play of individual fancy that its results could not quickly take fixed dogmatic shape, and it did not appeal to all minds alike or equally at all times It was in crises of national anguish that men turned most eagerly to the prophecies, and sought to construe their teachings as a promise of speedy deliverance in such elaborate schemes of the incoming of the future glory as fill the Apocalyptic Literature (*q v*) But these books, however influential, had no public authority, and when the yoke of oppression was lightened but a little their enthusiasm lost much of its contagious power It is not therefore safe to measure the general growth of eschatological doctrine by the apocalyptic books, of which Daniel alone attained a canonical position In the Apocrypha eschatology has a very small place, but there is enough to show that the hope of Israel was never forgotten, and that the imagery of the prophets had moulded that hope into certain fixed forms which were taken with a literalness not contemplated by the prophets themselves It was, however, only very gradually that the figure and name of the Messiah acquired the prominence which they have in later Jewish doctrine of the last things and in the official exegesis of the Targums In the very developed eschatology of Daniel they are, as we have seen, altogether wanting, and in the Apocrypha, both before and after the Maccabee revival, the everlasting throne of David's house is a mere historical reminiscence (Sirach xlvii 11, 1 Mac ii 57) So long as the wars of independence worthily occupied the energies of the Palestinian Jews, and the Hasmonæan sovereignty promised a measure of independence and felicity under the law, in which the people were ready to acquiesce, at least, till the rise of a new prophet (1 Mac xiv 41), the hope that connected itself with the house of David was not likely to rise to fresh life, especially as a considerable proportion of the not very numerous passages of Scripture which speak of the ideal king might with a little straining be applied to the rising star of the new dynasty (comp the language of 1 Mac xiv 4–15) It is only in Alexandria, where the Jews were still subject to the yoke of the Gentile, that at this time (*c* 140 B C) we find the oldest Sibylline verses (iii 652 *sq*) proclaiming the approach of the righteous king whom God shall raise up from the East (Isa xli 2) to establish peace on earth and inaugurate the sovereignty of the prophets in a regenerate world The name Messiah is still lacking, and the central point of the prophecy is not the reign of the deliverer but the subjection of all nations to the law and the temple [1]

---

[1] The hopes which Haggai and Zechariah connect with the name of Zerubbabel, a descendant of David, hardly form an exception to this statement

[2] See Joel, vol xiii p 706, and Stade s articles "Deuterozacharja," *Z f ATliche Wiss* , 1881-82 Compare Dan ix 2 for the use of the older prophecies in the solution of new problems of faith

With the growing weakness and corruption of the Hasmonæan princes, and the alienation of a large part of the nation from their cause, the hope of a better kingship begins to appear in Judæa also, at first darkly shadowed forth in the *Book of Enoch* (chap xc), where the white steer, the future leader of God's herd after the deliverance from the heathen, stands in a certain contrast to the inadequate sovereignty of the actual dynasty (the horned lambs), and then much more clearly, and for the first time with use of the name Messiah, in the *Psalter of Solomon*, the chief document of the protest of Pharisaism against its enemies the later Hasmonæans The struggle between the Pharisees and Sadducees, between the party of the scribes and the party of the Hasmonæan aristocracy, has been described in ISRAEL (vol xiii p 423 *sq*) It was a struggle for mastery between a secularized hierarchy on the one hand, to whom the theocracy was only a name, and whose whole interests were those of their own selfish politics, and on the other hand a party to which God and the law were all in all, and whose influence depended on the maintenance of the doctrine that the exact fulfilling of the law according to the precepts of the scribes was the absorbing vocation of Israel This doctrine had grown up in the political nullity of Judæa under Persian and Grecian rule, and no government that possessed or aimed at political independence could possibly show constant deference to the punctilios of the schoolmen The Pharisees themselves could not but see that their principles were politically impotent, the most scrupulous observance of the Sabbath, for example—and this was the culminating point of legality—could not thrust back the arms of the heathen Thus the party of the scribes, when they came into conflict with an active political power, which at the same time claimed to represent the theocratic interests of Israel, were compelled to lay fresh stress on the doctrine that the true deliverance of Israel must come from God and not from man We have seen indeed that the legalism which accepted Jehovah as legislator, while admitting that his executive sovereignty as judge and captain of Israel was for the time dormant, would from the first have been a self-destructive position without the complementary hope of a future vindication of divine justice and mercy, when the God of Israel should return to reign over his people for ever Before the Maccabee revival the spirit of nationality was so dead that this hope lay in the background, the ethical and devotional aspects of religion under the law held the first place, and the monotony of political servitude gave little occasion for the observation that a true national life requires a personal leader as well as a written law But now the Jews were a nation once more, and national ideas came to the front In the Hasmonæan sovereignty these ideas took a political form, and the result was the secularization of the kingdom of God for the sake of a harsh and rapacious aristocracy The nation threw itself on the side of the Pharisees, but it did so in no mere spirit of punctilious legalism, but with the ardour of a national enthusiasm deceived in its dearest hopes, and turning for help from the delusive kingship of the Hasmonæans to the true kingship of Jehovah, and to His vicegerent the king of David's house It is in this connexion that the doctrine and name of the Messiah appear in the *Psalter of Solomon* The eternal kingship of the house of David, so long forgotten, is seized on as the proof that the Hasmonæans have no divine right

> 'Thou Lord art our king for ever and ever Thou didst choose David as king over Israel, and swarest unto him concerning his seed for ever that his kingship should never fail before Thee And for our sins sinners (the Hasmonæans) have risen up over us, taking with force the kingdom which Thou didst not promise to them, profaning the throne of David in their pride But Thou O Lord will cast them down and root out their seed from the land, when a man not of our race (Pompey) rises up against them Behold O Lord, and raise up their king the Son of David at the time that Thou hast appointed to reign over Israel Thy servant and gird him with strength to crush unjust rulers to cleanse Jerusalem from the heathen that tread it under foot to cast out sinners from Thy inheritance to break the pride of sinners and all their strength as potter's vessels with a rod of iron (Ps ii 9) to destroy the lawless nations with the word of his mouth (Isa xi 4) to gather a holy nation and lead them in righteousness He shall divide them by tribes in the land, and no stranger and foreigner shall dwell with them he shall judge the nations in wisdom and righteousness The heathen nations shall serve under his yoke he shall glorify the Lord before all the earth, and cleanse Jerusalem in holiness as in the beginning From the ends of the earth all nations shall come to see his glory and bring the weary sons of Zion as gifts Isa lx 3 *sq*) to see the glory of the Lord with which God hath crowned him, for he is over them a righteous king taught of God In his days there shall be no unrighteousness in their midst for they are all holy, and their king the anointed of the Lord (χριστὸς κυριος a mistranslation of משיח יהוה) He shall not trust on horses and riders and bowmen, nor heap up gold and silver for war, nor put his confidence in a multitude for the day of war 'The Lord is king, that is his hope He is pure from sin to rule a great people to rebuke governors and destroy sinners by his mighty word. In all his days he is free from offence against his God for He hath made him strong by the Holy Spirit His hope is in the Lord who can do aught against him? Strong in deeds and mighty in the fear of the Lord, he feedeth the flock of the Lord in truth and righteousness, and suffereth not one of them to stumble in the pasture So it beseemeth the king of Israel whom God hath chosen to lead the house of Israel God hasten His mercy on Israel to deliver them from the uncleanness of profane foes. The Lord is our king for ever and ever'—*Psalt Sol* xvii

This conception is traced in lines too firm to be those of a first essay, it had doubtless grown up as an integral part of the religious protest against the Hasmonæans And while the polemical motive is obvious, and the argument from prophecy against the legitimacy of a non Davidic dynasty is quite in the manner of the scribes, the spirit of theocratic fervour which inspires the picture of the Messiah is broader and deeper than their narrow legalism In a word, the Jewish ~~doctrine~~ of the Messiah marks the fusion of Pharisaism with the national religious feeling of the

---

[1] In *Sibyll*, iii 775, νηόν must undoubtedly be read for υἱόν.

032 ENC V.16

SALAR JUNG LIBRARY 17497 | 300

Maccabee revival It is this national feeling that, claiming a leader against the Romans as well as deliverance from the Sadducee aristocracy, again sets the idea of the kingship rather than that of resurrection and individual retribution in the central place which it had lost since the captivity Henceforward the doctrine of the Messiah is at once the centre of popular hope and the object of theological culture The New Testament is the best evidence of its influence on the masses (see especially Matt xxi 9), and the exegesis of the Targums, which in its beginnings doubtless reaches back before the time of Christ, shows how it was fostered by the Rabbins and preached in the synagogues[1] Its diffusion far beyond Palestine, and in circles least accessible to such ideas, is proved by the fact that Philo himself (*De Præm et Pœn*, § 16) gives a Messianic interpretation of Num xxiv 27 (LXX) It must not indeed be supposed that the doctrine was as yet the undisputed part of Hebrew faith which it became when the fall of the state and the antithesis to Christianity threw all Jewish thought into the lines of the Pharisees It has, for example, no place in the *Assumptio Mosis* or the *Book of Jubilees* But, as the fatal struggle with Rome became more and more imminent, the eschatological hopes which increasingly absorbed the Hebrew mind all group themselves round the person of the Messiah In the later parts of the *Book of Enoch* (the "symbols" of chaps xlv *sq*) the judgment day of the Messiah (identified with Daniel's "Son of Man") stands in the forefront of the eschatological picture Josephus (*B J* vi 5, § 4) testifies that the belief in the immediate appearance of the Messianic king gave the chief impulse to the war that ended in the destruction of the Jewish state, after the fall of the temple the last apocalypses (*Baruch*, 4 *Ezra*) still loudly proclaim the near victory of the God sent king, and Bar Cochebas, the leader of the revolt against Hadrian, was actually greeted as the Messiah by Rabbi Akiba (comp Luke xxi 8) These hopes were again quenched in blood, the political idea of the Messiah, the restorer of the Jewish state, still finds utterance in the daily prayer of every Jew (the *Shmone Esre*), and is enshrined in the system of Rabbinical theology, but its historical significance was buried in the ruins of Jerusalem[2]

But the proof written in fire and blood on the fair face of Palestine that the true kingdom of God could not be realized in the forms of an earthly state, and under the limitations of national particularism, was not the final refutation of the hope of the Old Testament Amidst the last convulsions of political Judaism a new and spiritual conception of the kingdom of God of salvation, and of the Saviour of God's anointing, had shaped itself through the preaching, the death, and the resurrection of Jesus of Nazareth As applied to Jesus the name of Messiah lost all its political and national significance, for His victory over the world, whereby He approved himself the true captain of salvation, was consummated, not amidst the flash of earthly swords or the lurid glare of the lightnings of Elias, but in the atoning death through which He entered into the heavenly glory Between the Messiah of the Jews and the Son of Man who came not to be ministered to but to minister, and to give his life a ransom for many, there was on the surface little resemblance, and from their standpoint the Pharisees reasoned not amiss that the marks of the Messiah were conspicuously absent from this Christ But when we look at the deeper side of the Messianic conception in the *Psalter of Solomon*, at the heartfelt longing for a leader in the way of righteousness and acceptance with God which underlies the aspirations after political deliverance, we see that it was in no mere spirit of accommodation to prevailing language that Jesus did not disdain the name in which all the hopes of the Old Testament were gathered up The kingdom of God is the centre of all spiritual faith, and the perception that that kingdom can never be realized without a personal centre, a representative of God with man and man with God, was the thought, reaching far beyond the narrow range of Pharisaic legalism, which was the last lesson of the vicissitudes of the Old Testament dispensation, the spiritual truth that lay beneath that last movement of Judaism which concentrated the hope of Israel in the person of the anointed of Jehovah

It would carry us too far to consider in this place the details of the Jewish conception of the Messiah and the Messianic times as they appear in the later apocalypses or in Rabbinical theology See for the former the excellent summary of Schürer, *NTliche Zeitgeschichte*, §§ 28, 29 (Leipsic, 1874), and for the latter, besides the older books catalogued by Schürer (of which Schoettgen, *Horæ*, 1742, and Bertholdt, *Christologia Judæorum*, 1811, may be specially named), Weber, *Altsynagogale Theologie* (Leipsic 1880) For the whole subject see also Drummond, *The Jewish Messiah* (London, 1877), and Kuenen, *Religion of Israel* chap xii For the Messianic hopes of the Pharisees and the *Psalter of Solomon* see especially Wellhausen, *Pharisäer und Sadducäer* (Greifswald, 1874) In its ultimate form the Messianic hope of the Jews is the centre of the whole eschatology, embracing the doctrine of the last troubles of Israel (called by the Rabbins the "birth pangs of the Messiah"), the appearing of the anointed king, the annihilation of the hostile enemy the return of the dispersed of Israel the glory and world-sovereignty of the elect, the new world, the resurrection of the dead, and the last judgment But even the final form of Jewish theology shows much vacillation as to these details, especially as regards their sequence and mutual relation, thus betraying the inadequacy of the harmonistic method by which they were derived from the Old Testament and the stormy excitement in which the Messianic idea was developed It is, for example, an open question among the Rabbins whether the days of the Messiah belong to the old or to the new world (הָעולם הזה or הָעולם הבא), whether the resurrection embraces all men or only the righteous, whether it precedes or follows the Messianic age Compare MILLENNIUM

We must also pass over the very important questions that arise as to the gradual extrication of the New Testament idea of the Christ from the elements of Jewish political doctrine which had so strong a hold of many of the first disciples—the relation, for example of the New Testament Apocalypse to contemporary Jewish thought A word, however, is necessary as to the Rabbinical doctrine of the Messiah who suffers and dies for Israel, the Messiah son of Joseph or son of Ephraim, who in Jewish theology is distinguished from and subordinate to the victorious son of David The developed form of this idea is almost certainly a product of the polemic with Christianity, in which the Rabbins were hard pressed by arguments from passages (especially Isa liii) which their own exegesis admitted to be Messianic, though it did not accept the Christian inferences as to the atoning death of the Messianic king That the Jews in the time of Christ believed in a suffering and atoning Messiah is, to say the least, unproved and highly improbable See, besides the books above cited, De Wette *Opuscula*, Wunsche, *Die Leiden des Messias*, 1870 The opposite argument of King, *The Yalkut on Zechariah* (Cambridge, 1882), App A, does not really prove more than that the doctrine of the Messiah Ben Joseph found points of attachment in older thought (W R S)

MESSINA, a city and seaport at the north east corner of Sicily, capital of the province of the same name,[3] is•

---

[1] The Targumic passages that speak of the Messiah are registered by Buxtorf, *Lex Chald*, s v

[2] False Messiahs have continued from time to time to appear among the Jews Such was Serenus of Syria (*circa* 720 A D) Soon after Messianic hopes were active at the time of the fall of the Omayyads, and led to a serious rising under Abu Isa of Ispahan, who called himself forerunner of the Messiah The false Messiah David Alrui (Alroy) appeared among the warlike Jews in Azerbijan in the middle of the 12th century The Messianic claims of Abraham Abulafia of Saragossa (born 1240) had a cabalistic basis and the same studies encouraged the wildest hopes at a later time Thus Abarbanel calculated the coming of the Messiah for 1503 A D, the year 1500 was in many places observed as a preparatory season of penance, and throughout the 16th century the Jews were much stirred and more than one false Messiah appeared. For the false Messiah Sabbathai, see vol xiii p 681

[3] The province occupies the north east corner of the island, and is 60 miles in length by 30 in breadth It is chiefly occupied with mountain ranges and valleys, there are few plains The largest river is the

situated on the Straits of Messina (at this point about 4 miles wide), 8 miles north-west of Reggio and 130 miles east by north of Palermo, in 38° 15′ N. lat., 15° 30′ E. long. The town is built between the sea and a range of sharp and rugged hills, called the Dinnamare, 3707 feet at their highest point. It runs in a semicircle round the harbour, and presents a picturesque appearance from the sea, as the houses rise in tiers upon the slope of a hill, and behind are the wooded mountains.

Messina is the second town of Sicily in importance and in size. Its population was 97,074 in 1850, 111,854 in 1871, and 126,497 in 1881. It is an archiepiscopal see, and has a university, founded by the Jesuits in 1548, with a public library of 56,000 volumes.

The excellence of its harbour makes Messina an important trading town. The harbour is formed by a tongue of low land which runs out from the shore in the form of a sickle, and encloses a round basin, open to the north only, where the entrance channel is about 500 yards wide. This basin is 1¼ miles in circumference, and is of such depth that the largest vessels are able to use it. It is estimated that 1300 steamers, with a total of 1,000,000 tons burthen, and 9000 sailing ships, with a total of 500,000 tons burthen, enter the port yearly. The exports of Messina consist chiefly of oranges, lemons, raisins, wine, oil, liquorice, and hides. There is no prominent manufacture, but silk stuffs are made in considerable quantities. Many of the inhabitants are engaged in fishing, chiefly for tunny. Sword fish also are captured with the harpoon in the Straits during July and August. Coral fishery is a trade of the people. The hills behind Messina produce a strong dark wine, inferior to that which is made in other parts of the island.

Messina has few buildings of importance or antiquity. The sieges and earthquakes from which the town has suffered destroyed most of its monuments. After the great earthquake in 1783 the city was almost entirely rebuilt. The cathedral, the principal building, is a church of the Norman period. It was begun in 1098 by Count Roger I., and finished by his son Roger II. The church is in the form of a Latin cross, 305 feet long and 145 feet wide in the transepts. The lower half of the façade is encrusted with slabs of red and white marble. It has three Gothic portals, with pointed arches and rich ornamentation, belonging to the period of the Anjou dynasty. The nave contains twenty-six columns of Egyptian granite, said to have been brought from an ancient temple of Poseidon which stood near the Faro. The mosaics of the apses date from the year 1330. In the choir are the sarcophagi of the emperor Conrad IV. (d. 1254), of Alphonso the Generous (d. 1458), and of Antonia, widow of Frederick III. of Aragon. In 1254 the cathedral was seriously damaged by fire; in 1559 the campanile was burned down; in 1783 the earthquake overthrew the campanile and the transept. The building therefore offers a mixture of styles,—first Norman, then Gothic, then Early Renaissance, finally Barocco and Modern Gothic.

The history of Messina begins very early. It is said to have been founded, on the site of a more ancient Sicilian town, by pirates from Cumæ, in 732 B.C. It took its earlier name of Zancle (a sickle) from the shape of its harbour. The number of its inhabitants was increased by an influx of Chalcidians under Cratæmenes, and in 649 B.C. the town was sufficiently prosperous and populous to establish a colony at Himera. The Samians occupied Zancle for a short time after Miletus had been captured by the Persians in 494 B.C. In the following year the city fell into the hands of Anaxilas, tyrant of Rhegium, who introduced a population of Messenians, from Messenia in the Peloponnesus, and they changed the name of the place to Messana, in the Doric pronunciation, to remind them of their fatherland. The sons of Anaxilas were expelled from the government of Messina in 466 B.C., and a republic established, and this government was continued until Messina fell into the hands of the Carthaginians during their wars with Dionysius the elder of Syracuse (396 B.C.). The Carthaginians destroyed the city, but Dionysius recaptured and rebuilt it. During the next fifty years Messina changed masters several times, till Timoleon finally expelled the Carthaginians in 343 B.C. In the wars between Agathocles of Syracuse and Carthage, Messina took the side of the Carthaginians. Agathocles's mercenaries, the Mamertines, treacherously seized the town in 288 B.C. and held it. They came to war with Hiero II. of Syracuse, after Agathocles's death, and Hiero's allies, the Carthaginians, helped him to reduce Messina. The Mamertines appealed for help to Rome, which was granted, and this led to a collision between Rome and Carthage, which ended in the First Punic War. At the close of that war in 241 B.C., Messina became a possession of the Romans. During the civil wars which followed the death of Julius Cæsar Messina held with Sextus Pompeius, and in 35 B.C. it was sacked by Octavian's troops. After Octavian's proclamation as emperor he founded a colony here, and Messina continued to flourish as a trading port. In the division of the Roman empire it belonged to the emperors of the East, and in 547 A.D. Belisarius collected his fleet here before crossing into Calabria. The Saracens took the city in 831 A.D., and in 1061 it was the first permanent conquest made in Sicily by the Normans under Roger d'Hauteville. In 1190 Richard Cœur de Lion with his crusaders passed six months in Messina. He fell out with Tancred, the last of the Hauteville dynasty, and sacked the town. In 1194 the city, with the rest of Sicily, passed to the house of Hohenstaufen under the emperor Henry VI., who died there in 1197. At the time of the Sicilian Vespers (1282) which drove the French out of Sicily, Messina bravely defended itself against Charles of Anjou, and repulsed his attack. Peter I. of Aragon, through his commander Ruggiero di Loria, defeated the French off the Faro, and from 1282 to 1713 Messina remained a possession of the Spanish royal house. In 1571 the fleet fitted out by the Holy League against the Turk assembled at Messina, and in the same year its commander, Don John of Austria, celebrated a triumph in the city for his victory at Lepanto. Don John's statue stands in the Piazza dell' Annuziata. For one hundred years, thanks to the favours and the concessions of Charles V., Messina enjoyed great prosperity. But the internal quarrels between the Merli, or aristocratic faction, and the Malvezzi, or democratic faction, fomented as they were by the Spaniards, helped to ruin the city (1671–78). The Messinians suspected the Spanish court of a desire to destroy the ancient senatorial constitution of the city, and sent to France to ask the aid of Louis XIV. in their resistance. Louis despatched a fleet into Sicilian waters, and the French occupied the city. The Spaniards replied by appealing to Holland, who sent a fleet under Ruyter into the Mediterranean. The French admiral, Duquesne, defeated the combined fleet of Spain and Holland, but, notwithstanding this victory, the French suddenly abandoned Messina in 1678, and the Spanish occupied the town once more. The senate was suppressed, and Messina lost its privileges. This was fatal to the importance of the city, and it never recovered. In 1743 the plague carried off 40,000 inhabitants. The city was partially destroyed by earthquake in 1783. During the revolution of 1848 against the Bourbons of Naples, Messina was bombarded for three consecutive days. In 1854 the deaths from cholera numbered about 15,000. Garibaldi landed in Sicily in 1860, and Messina was the last city in the island taken from the Bourbons and made a part of united Italy under Victor Emmanuel.

Messina was the birthplace of the following celebrated men:—Dicæarchus, the historian (*cir.* 322 B.C.), Aristocles the Peripatetic, Euhemerus, the rationalist (*cir.* 316 B.C.), Stefano Protonotario, Mazzeo di Ricco, and Tommaso di Sasso, poets of the court of Frederick II. (1250 A.D.), and Antonello da Messina, the painter (1447–99), five of whose works are preserved in the university gallery. During the 15th century the grammarian Constantine Lascaris taught in Messina, and Bessarion was for a time archimandrite there.

METALLURGY, a branch of applied science whose object is to describe and scientifically criticize the methods used industrially for the extraction of metals from their ores. Of the large number of metals enumerated in the handbooks of chemistry, the vast majority, of course, lie outside its range; but it is perhaps as well for us to point out that in metallurgic discussions even the term "metallic," as applied to compounds, has a restricted meaning, being exclusive of all the light metals, although one of these, namely aluminium, is being manufactured industrially. The following table enumerates in the order of their importance the metals which our subject at present

---

Alcantara. The chief towns are Messina, Castroreale, Mistretta, Patti, and Milazzo. The population in 1854 was 380,279, in 1871 420,649, and in 1881 467,233.

is understood to include, the second column in each case gives the chemical characters of the native compounds utilized, italics indicating ores of subordinate importance The term "oxide' must be understood to include carbonate, hydrate, and occasionally (when marked in the table with *) silicate

Metal	Character of Ores
Iron	Oxides, *sulphide*
Copper	Complex sulphides, also oxides, *metal*
Silver	Sulphide and reguline metal, *chloride*
Gold	Reguline metal
Lead	Sulphide and basic carbonate, *sulphate* &c
Zinc	Sulphide, oxide *
Tin	Oxide
Mercury	Sulphide reguline metal
Antimony	Sulphide
Bismuth	Reguline metal
Nickel and cobalt	Arsenides
Platinum and platinum metals	Reguline
Aluminium	Oxide * sodio fluoride

We have separated the last two from the rest because the methods used for their preparation are more of the character of laboratory operations, and because we do not mean to include these in our general exposition of metallurgic principles The history of metallurgy, up to the most recent times, is obscure It is only since about the beginning of this century that the art has come to be at all scientifically criticized and in the case of the most important processes all that science has been able to do has been merely to put her stamp upon what experience has long found to be right Great and brilliantly successful scientific efforts in the synthetic line are not wanting but they all belong to recent times Science, by its very nature aims at publicity, empiricism at all times has done the reverse, hence a history of the development of the art of metallurgy does not and cannot exist A few historical notes on the discovery of certain of the useful metals are given in the introduction to METALS (*q v*)

General Sequence of Operations—Occasionally metallic ores present themselves in the shape of practically pure compact masses from which the accompanying matrix or "gangue can be detached by hand and hammer But this is a rare exception In most cases the "ore, as it comes out of the mine, is simply a mixture of ore proper and gangue in which the latter not unfrequently predominates so much that it is not the gangue but the ore that really occupies the position of what the chemist would call the impurity Hence, in general it is necessary, or at least expedient to purify the ore as such before the liberation of the metal is attempted Most metallic ores are specifically heavier than the impurities accompanying them, and their purification may be (and generally is) effected by reducing the crude ore to a fine enough powder to detach the metallic from the earthy part, and then washing away the latter by a current of water, as far as possible In the case of a "reguline" ore, such as auriferous quartz, for instance, the ore thus concentrated may consist substantially of the metal itself, and require only to be melted down and cast into ingots to be ready for the market This, however, is a rare case, the vast majority of ores being chemical compounds, which for the extraction of their metals demand chemical treatment The chemical operations involved may be classified as follows —

1 *Fiery Operations*—The ore, along in general with some kind of "flux," is exposed to the direct action of a powerful fire The fire in most cases has a chemical, in addition to its obvious physical function It is intended either to burn away certain components of the ore—in which case it must be so regulated as to contain a sufficient excess of unburned oxygen, or it is meant to deoxidize ("reduce") the ore, when the draught must be restricted so as to keep the ore constantly wrapped up in combustible flame gases (carbonic oxide, hydrogen, marsh gas, &c) The vast majority of the chemical operations of metallurgy fall into this category, and in these processes other metal reducing agents than those naturally contained in the fire (or wind) are only exceptionally employed

2 *Amalgamation*—The ore by itself (if it happens to be a reguline one), or the ore plus certain reagents (if it does not), is worked up with mercury so that the metal is obtained ultimately as an amalgam, which can be separated mechanically from the dross The purified amalgam is subjected to distillation, when the mercury is recovered as a distillate while the metal remains

3 *Wet Processes*—Strictly speaking, certain amalgamation methods fall under this head, but, in its ordinary acceptance, the term refers to processes in which the metal is extracted either from the natural ore, or from the ore as it is after roasting or some other preliminary treatment, by means of an aqueous acid or salt solution, and from this solution precipitated—generally in the reguline form—by some suitable reagent

Few methods of metal extraction at once yield a pure product What as a rule is obtained is a more or less impure metal, which requires to be "refined to become fit for the market We now pass to the individual consideration of the several steps referred to

Comminution of Ores—Assuming the ore to be given in the shape of large lumps these must first be broken up into small stones (of about the size of those used for macadamizing a road) before they can go to the grinding mill This formerly used to be done by hand work nowadays it is preferably effected by means of an American invention called the stone breaker (fig 1) This consists essentially of two substantial vertical iron plates one is fixed the other is connected with an excentric worked by an engine so as to alternately dash against and recede from the former The lumps of ore in passing through this jaw like contrivance, are broken up into smaller fragments fit for the mill For the production of a coarse powder revolving cylinders are often employed Two cylinders of equal diameter and length, made of iron steel, or stone are suspended by parallel axes in close proximity to each other The width of the slit between them can be made to vary according to the requirements of the case The cylinders are made to revolve in opposite directions, so that the stones when run into the groove formed by their upper halves are drawn between them and are crushed into bits of a size depending on the least distance between the two surfaces Exceptionally hard stones might bring the machine to a standstill or cause breakages hence only one of the two axes of rotation is absolutely fixed the cushions of the other are only held in relatively fixed positions, each between a couple of guiding rails, by means of powerful springs at their backs The springs are made of alternate disks of india rubber and sheet iron and yield appreciably only to very strong pressures When an exceptionally hard stone comes on, they yield

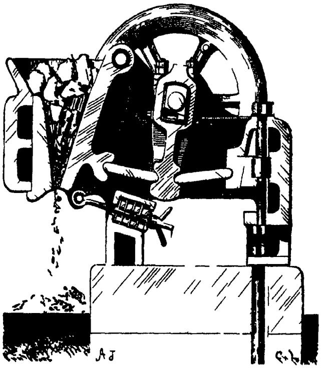


FIG 1 —American Stone Breaker

and allow it to pass through uncrushed Sometimes two sets of cylinders are arranged one above the other, so that the grit from the upper falls into the jaws of the lower set to receive further comminution The diameter of the cylinders is from a foot to a yard, their length from 9 inches to a yard, the velocity of a point on the periphery a foot to a yard per second The quantity of ore reduced per hour per horse power is about 5 cubic feet for quartz or other hard minerals, and about 14 cubic feet for minerals of moderate hardness

For the production of a relatively fine powder the pounding mill is frequently used, which, in its action, is analogous to a mortar and pestle The mortar is a rectangular trough, while the pestle is replaced by a parallel set of heavy metal or metal shod beams, which (by means of a revolving cylinder with cogs catching projections on the beams) are lifted up in succession and then let fall by their own weight so as to pound up the ore in the trough The ore is supplied from a prismatic reservoir with a sloping bottom leading into a canal through which the stones slide into the trough A current of water, which constantly flows into the trough from below, lifts up the finer particles and carries them away over the edge of the trough into a settling tank

The object pursued in powdering an ore is to prepare it for being purified by washing But the velocity with which a solid particle falls through water depends on its size as well as on its specific gravity—an increase in either accelerating the fall, hence, where the difference in specific gravity between the things to be separated is small, the washing must be preceded by a separation of the ore powder into portions of approximately equal fineness This is often effected by passing the ore through a system of sieves of different width of mesh superposed over one another, the coarser sieve always occupying the higher position Sometimes the sieves are made to "go dry," sometimes they are aided in their action by a current of water which, more effectually than mere shaking, prevents adherence of dust to coarser parts

Another contrivance is the "Drum (fig 2) A long perforated circular cylinder made of sheet iron, open at both ends, is suspended, in a sloping position, by a revolving shaft passing through its axis The size of the perforations is generally made to increase in passing from the upper to the lower belts of the cylinder While the drum is revolving the ore, suspended in water, flows in at the upper end, and in travelling down it casts off first its finest and then its coarser parts, the coarsest only reaching the exit at the lower end The several grades of powder produced fall each into a separate division of the collecting tank

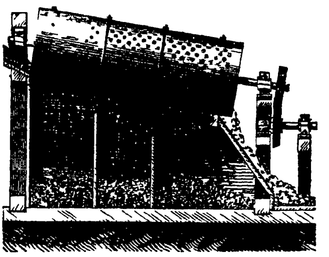


Fig 2 —Drum

The drum, of course, is subject to endless modifications. A very ingenious combination is H E Taylor's "Drum Dressing Machine ' (fig 3) It consists of three truncated cone shaped drums D, fixed co axially to the same horizontal revolving shaft, so that the narrow end of No 1 projects into the wider end of No 2, and No 2 similarly into No 3 The drums are not perforated, but are armed inside with screw threads formed of strips of sheet metal fixed edgeways to the drum The ore grit to be dressed is placed in a hopper A, and from it, by a worm B fixed to the revolving shaft, is being screwed forward into a short fixed truncated cone C projecting into the revolving drum No 1, into which it flows in a constant current The rotary motion of the drum tends to convey the ore along the spiral path prescribed by the screw thread towards the other end, and from it into drum No 2, and so on But the ore in each drum meets with a jet of water L impelling it the opposite way, and the effect is that, in each drum, the lighter parts follow the water, and with it run off over the entrance edge to be collected in a special tank, while the coarser parts roll down the spiral path toward the next drum to undergo further parting The tank or pit for drum 1 receives the finest and lightest parts, that of drum 2 a heavier, that of drum 3 a still heavier portion, while only the very heaviest matter finds its way out of the exit end of No 3 into a fourth receptacle

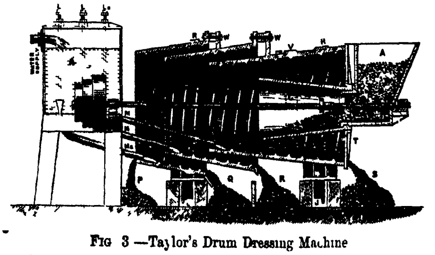


Fig 3 —Taylor's Drum Dressing Machine

Of the large number of other ore-dressers, only two need be mentioned here

The "Clausthal Turn-Table ' consists of a circular table the surface of which rises from the periphery towards the centre so as to form a very flat cone of about 170°, which is fixed co axially to a vertical rotary shaft At the apex of the table, surrounding the shaft, but independent of its motion, there is a circular trough of sheet zinc, divided into two compartments, one receives a stream of water carrying the ore, the other a supply of pure water A large annular trough of sheet zinc is placed below the periphery of the table, so as to receive whatever may fall over the edge It also is divided into compartments, as shall be explained further on Supposing the table to be at rest, a sector of about 60° of it would be constantly run over by the ore mud out of the first compartment of the upper trough This mud current would suffer partial separation into heavier and lighter parts,—rich ore resting in the higher and poorer in the lower latitudes, and a still poorer ore falling over the periphery into the lower trough The same happens with the moving table, only each sector of such partially analysed ore undergoes further purification by passing through about 90° of water shower After passing this, it meets with a perforated fixed water pipe going up radially to about half the radius of the table This pipe also carries sweeping brushes, so that the belt of ore from the lower latitudes of the table is swept off into the corresponding section of the receiving trough What of ore remains on the higher latitudes subsequently meets with a similar arrangement which sweeps it off into its compartment If the table turns from the left to the right, and we follow the process, beginning at the left edge of the ore mud compartment, it will be seen that a first sector of the receiving trough gathers the light dross, a succeeding one an intermediate product, a third the most highly purified ore The ' intermediate ' is generally run into the ore mud trough of a second table to be further analysed

In the ' Continuous Wash Pumps' (Continuirliche Setzpumpe) of the Harz, three funnel shaped vessels (one of which is shown in fig 4) are set in a frame beside one another, but at different levels, so that any overflow from No 1 runs into No 2 and thence into No 3 Each funnel communicates below with its own compartment of a common cistern Into each funnel a riddle with narrow meshes is inserted somewhere near the upper end, while, beside the riddle, there is a pump of short range, which, by means of an excentric, is worked so that the piston alternately goes rapidly down and slowly up The mode of working is best explained by an example At Breinigerberg in Rhenish Prussia the apparatus serves to separate a complex ore into the following four parts, which we enumerate in the order of their specific gravities—(1) galena (the heaviest), (2) pyrites, (3) blende, (4) dross Sieve No 1 is charged with granules of galena, just large enough not to slip through the meshes, No 2 similarly with granules of pyrites, No. 3 with those of blende The crude ore mud goes into sieve 1, the jerking action of the pump alternately tosses the particles up into the water and allows them to fall the heaviest naturally come down first, but what is most striking is that nothing will pass through the bed of galena but what is at least as heavy as galena itself In a similar manner No 2 and No. 3

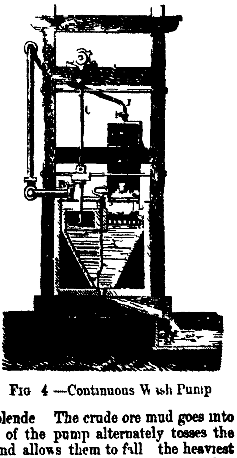


Fig 4 —Continuous Wash Pump

funnels sift out the pyrites and the blende respectively, so that almost nothing but dross runs off ultimately The apparatus is said to do its work with a wonderful degree of precision, and of course is susceptible of wider application, but it ceases to work when the raw material is a slime so fine that the particles fall too slowly

Modes of Producing High Temperatures —Most of what is to be said on this topic has already been anticipated in the articles FUEL, FURNACE, and BELLOWS, but a few notes may be added on specially metallurgic points

Furnace Materials —In a metallurgic furnace the working parts at least must be made of special materials capable of withstanding the very high temperatures to which they are exposed and the action of the fluxes which may be used No practically available material fully meets both requirements, but there is no lack of merely fire proof substances

Of native stones, a pure quartzose sandstone, free from marl, may be named as being well adapted for the generality of structures but such sandstone, or indeed any kind of fire proof stone, is not always at hand What is more readily procured, and consequently more widely used, is refractory brick, made from "fire clay" The characteristic chemical feature of fire clays is that in them the clay proper (always some kind of hydrated silicate of alumina) is associated with only small proportions of lime, magnesia, ferrous oxide, or other protoxides If the percentage of these goes beyond certain limits, the bricks when strongly heated melt down into a slag The presence of free silica on the other hand adds to their refractoriness In fact the best fire bricks in existence are the so called Dinas bricks, which consist substantially of silica contaminated only with just enough of bases to cause it to frit together on being baked Dinas bricks, however, on account of their high price, are reserved for special cases involving exceptionally high temperatures Amongst ordinary fire bricks those from Stourbridge enjoy the highest reputation It follows from what has just been said that, in a metallurgic furnace, lime mortar cannot be used as a cement, but must be replaced by fire clay paste

In the construction of cupels, reverberatory furnaces, &c, only the general groundwork is, as a rule, made of built bricks, and this groundwork is coated over with some kind of special fire proof and flux proof material such as bone ash, a mixture of baked fire clay and cokes or graphite or of quartz and very highly silicated slags, &c These beddings are put on in a loose powdery form, and then stamped fast They offer the advantage that when worn out, they are easily removed and renewed The powerful draught which a metallurgic fire needs can be produced by a chimney, where the fuel forms a relatively shallow layer spread over a large grating, but, when closely packed deep masses of fuel or fuel and ore have to be kept ablaze, a blast becomes indispensable

Chimneys —The efficiency of a chimney is measured by the velocity V with which the air ascends through it, multiplied by its section, and the former is in roughly approximate accordance with the formula

$$V=k\sqrt{2gh(T-T_0)/T_0},$$

where *h* stands for the height of the chimney, *g* for the acceleration of gravity (32 2 feet per second), and T and T_0 for the absolute temperatures (meaning the temperatures counted from − 273° C) of the air within and the air without the chimney respectively, while *k* is a factor meant to account for the resistances which the air, in its progress through the furnace, &c, has to overcome In practice T is taken as the mean temperature of the chimney gases, which theoretically is not unobjectionable, but the weakest point in the formula is the smallness and utter inconstancy of the factor *k*, which, according to Péclet, generally assumes some value of the power $\frac{1}{3}$, $\frac{1}{4}$, &c Yet the formula is of some use as enabling one to see the way in which V depends on *h* and $(T-T_0)/T_0$ conjointly,—to see, for instance, how deficient chimney height may be compensated for by an increase of temperature in the chimney gases, and *vice versa*

Blowing Machines —Of the several kinds of blowers described under BELLOWS (*q v*), the "fans" are the best means for producing large volumes of wind of relatively small but steady pressure, "bellows" are indicated in the case of work on a relatively small scale requiring moderate wind pressure, while the "cylinder blast" comes in where large masses of high pressure wind are required Two highly interesting blowing machines, however, are omitted in that article, which may be shortly described here

The "Water Blast" (Wassertrommelgeblase) is interesting historically, having been used metallurgically in Hungary for many centuries A mass of water, stored up in a reservoir, is made to fall down continuously through a high narrow vertical shaft having air holes at its upper end The vertical column of water sucks in air through these holes and carries it down with it into a kind of inverted tub standing in a reservoir kept at a constant level Air and water there separate, the former flowing away through a pipe into a wind-box from which it is led to its destination

The "Cagniardelle" (figs 5, 6), so called from its inventor Cagniard Latour, also utilizes water to carry air, but in quite another way By means of a round shaft passing through its axis, a cylindrical drum of sheet metal is suspended slantingly in a mass of water, so that the lower end is fully immersed, while of the upper end the segment above the upper side of the shaft is uncovered. The space between shaft and drum is converted into a very wide screw-shaped canal by a band of sheet metal hermetically fixed edgeways to the two Both the top and the bottom end of the drum are partially closed by flat bottoms soldered or riveted to the respective edges, the lower one leaves a ring shaped opening between its edge and the shaft, which serves for the introduction of a fixed air pipe bent so as to reach up to near the top of the drum's air space, in the upper bottom three quadrants are closed, the fourth is open Supposing the screw canal traced from below, to go from the left to the right, the drum is made to revolve in the same sense, and the effect is that, in each revolution the screw canal at its top end swallows a certain volume of air which, by the succeeding entrance of the water—which, of course, moves relatively to the screw—is pushed towards and ultimately into the air space at the bottom end The Cagniardelle yields a perfectly continuous blast, and, as it is not encumbered with any dead resistances except the friction of the shaft against its bearings (which can be reduced to very little) and the very slight friction of the water against the screw canal, it utilizes a very large percentage of the energy spent on it This percentage, according to experiments by Schwamkrug, amounts to from 75 to 84 5, in the case of the cylinder blast it is 60 to 65 per cent, with bellows, about 40 per cent, with the "Wassertrommelgeblase" 10 to 15 per cent Hence the "Wassertrommelgeblase" stands last in relative efficiency, but we must not forget that it alone directly utilizes native energy, while, in the cylinder blast, for example, 100 units of work done by the steam engine involve a vastly greater energy spent on the engine as heat

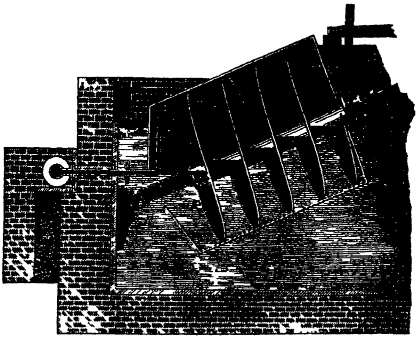


FIG 5 —Cagniardelle

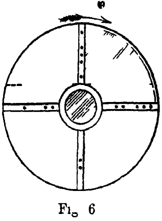


Fig 6

To maintain a desired temperature in a given furnace charged in a certain manner, the introduction of a certain volume of air per unit of time is necessary But this quantity, in a given blowing machine, is determined by the over pressure of the wind, as measured by a manometer, the velocity of the wind being approximately proportional to $\sqrt{M/(B+M)}$, where M stands for the height of the mercury manometer, and B for that of the barometer Hence the practical metallurgist, in adjusting his blast, has nothing to do but to see that the manometer shows the reading which, by previous trials, has been proved to yield an adequate supply of wind

Fuel —In some isolated cases the ore itself, by its combustion, supplies the necessary heat for the operation to be performed upon it Thus, for instance, the roasting of blackband iron stone is effected by simply piling up the ore and setting fire to it, so that the ore is at the same time its own furnace and fuel, in the Bessemer process of steel making, the burning carbon of the pig iron supplies the heat necessary for its own combustion, and a similar process has been tried experimentally, and not without success, for the working up of certain kinds of pyrites But, as a rule, the high temperatures required for the working of ores are produced by the combustion of extraneous fuel, such as wood, wood-charcoal, coal, coke Of these four, wood charcoal is of the widest applicability, but not much used in Britain on account of its high price High-class coke or pure anthracite, volume for volume, gives the highest temperature Wood or coal is indicated when a voluminous flame is one of the requisites Obviously fuel of the same kind and quality gives a higher calorific intensity when, before use, it is deprived by drying of its moisture, or when it is used in conjunction with a hot instead of a cold blast This latter principle, as every one knows, is largely discounted in the manufacture of pig iron, where nowadays coal, with the help of the hot blast, is made to do what formerly could only be effected with charcoal or coke For further information see FUEL and IRON

Chemical Operations —In regard to processes of amalgamation and to wet way processes, we have nothing to add to what was given in a previous paragraph ,[1] we therefore here confine ourselves, in the main, to pyro chemical operations

The method to be adapted for the extraction of a metal from its ore is determined chiefly, though not entirely, by the nature of the non metallic component with which the metal is combined The simplest case is that of the reguline ores where there is no non-metallic element The important cases are those of GOLD, BISMUTH, and MERCURY (*q v*)

Oxides, Hydrates, Carbonates, and Silicates —All iron and tin ores proper fall under this heading, which, besides, comprises certain ores of copper, of lead, and of zinc In any case the first step consists in subjecting the crude ore to a roasting process, the object of which is to remove the water and carbonic acid, and burn away, to some extent at least, what there may be of sulphur, arsenic, or organic matter The residue consists of an impure (perhaps a very impure) oxide of the respective metal, which in all cases is reduced by treatment with fuel at a high temperature Should the metal be present in the silicate form, lime must be added in the smelting to remove the silica and liberate the oxide

In the case of zinc the temperature required for the reduction lies above the boiling point of the metal , hence the mixture of ore and reducing agent (charcoal is generally used) must be heated in a retort combined with the necessary condensing apparatus In all the other cases the reduction is effected in the fire itself, a tower shaped blast furnace being preferably used The furnace is charged with alternate layers of fuel and ore (or rather ore and flux, see below), and the whole kindled from below The metallic oxide, partly by the direct action of the carbon with which it is in contact, but principally by that of the carbonic oxide produced in the lower strata from the oxygen of the blast and the hot carbon there, is reduced to the metallic state , the metal fuses and runs down, with the slag, to the bottom of the furnace, whence both are withdrawn by the periodic opening of plug holes provided for the purpose

Sulphides —Iron, copper, lead, zinc, mercury, silver, and antimony very frequently present themselves in this state of combination, as components of a very numerous family of ores which may be divided into two sections (1) such as substantially consist of simple sulphides, as iron pyrites (FeS_2), galena (PbS), zinc blende (ZnS), cinnabar (HgS) , and (2) complex sulphides, such as the various kinds of sulphureous copper ores (all substantially compounds or mixtures of sulphides of copper and iron) , bournonite, a complex sulphide of lead, antimony, and copper , rothgiltigerz, sulphide of silver, antimony, and arsenic fahlerz, sulphides of arsenic and antimony, combined with sulphides of copper, silver, iron, zinc, mercury, silver , and mixtures of these and other sulphides with one another

In the treatment of a sulphureous ore, the first step as a rule is to subject it to oxidation by roasting it in a reverberatory or other furnace, which, in the first instance, leads to the burning away of at least part of the arsenic and part of the sulphur The effect on the several individual metallic sulphides (supposing only one of these to be present) is as follows —

1 Those of silver (Ag_2S) and mercury (HgS) yield sulphurous acid gas and metal , in the case of silver, sulphate is formed as an intermediate product, at low temperatures Metallic mercury, in the circumstances, goes off as a vapour, which is collected and condensed , silver remains as a regulus, but pure sulphide of silver is hardly ever worked

2 Sulphides of iron and zinc yield the oxides Fe_2O_3 and ZnO as final products, some basic sulphate being formed at the earlier stages, more especially in the case of zinc The oxides can be reduced by carbon

3 The sulphides of lead and copper yield, the former a mixture of oxide and normal sulphate, the latter one of oxide and basic sulphate Sulphate of lead is stable at a red heat , sulphate of copper breaks up into oxide, sulphurous acid, and oxygen In practice, neither oxidation process is ever pushed to the end , it is stopped as soon as the mixture of roasting product and unchanged sulphide contains oxygen and sulphur in the ratio of O_2 S The access of air is then stopped and the whole heated to a higher temperature, when the potential SO_2 actually goes off as sulphurous acid gas and the whole of the metal is eliminated as such This method is largely utilized in the smelting of lead (from galena) and of copper from copper pyrites In the latter case, however, the sulphide Cu_2S has first to be produced from the ore, which is done substantially as follows The ore is roasted with silica until a certain proportion of the sulphur is burned away as SO_2, while a corresponding proportion of oxygen has gone to the metal part of the ore Now it so happens that copper has a far greater affinity for sulphur than iron has , hence any locally produced oxide of copper, as long as sufficient sulphide of iron is left, is sure to be reconverted into sulphide, and the final result is that, while a large quantity of oxidized iron passes into the slag, all the copper and part of the iron separate out as a mixed regulus of Cu_2S and FeS ("mat') This regulus, by being fused up repeatedly with oxidized copper ores or rich copper slags (virtually with CuO and silica), gradually yields up the whole of its iron, so that ultimately a regulus of pure subsulphide of copper, Cu_2S ("fine mat), is obtained, which is worked up for metal as above explained

4 Sulphide of antimony, when roasted in air, is converted into a kind of alloy of sulphide and oxide , the same holds for iron, only its oxysulphide is quite readily converted into the pure oxide Fe_2O_3 by further roasting Oxysulphide of antimony, by suitable processes, can be reduced to metal, but these processes are rarely used, because the same end is far more easily obtained by "precipitation," *i e* , withdrawing the sulphur by fusion with metallic iron, forming metallic antimony and sulphide of iron Both products fuse, but readily part, because fused antimony is far heavier than fused sulphide of iron is A precisely similar method is used occasionally for the reduction of lead from galena. Sulphide of lead when fused together with metallic iron in the proportion of 2Fe 1PbS yields a regulus (=1Pb) and a "mat" Fe_2S, which, however, on cooling, decomposes into FeS parts of ordinary sulphide and Fe parts of finely divided iron What we have just been explaining are only two special cases of a more general metallurgic proposition According to Fournet, any one of the metals copper, iron, tin, zinc, lead, silver, antimony, arsenic, in general, is capable of desulphurizing or precipitating (at least partially) any of the others that follows it in the series just given, and it does so the more readily and completely the greater the number of intervening terms Hence, supposing a complete mixture of these metals to be melted down under circumstances admitting of only a partial sulphuration of the whole, the copper has the best chance of passing into the "mat," while the arsenic is the first to be eliminated as such, or, in the presence of oxidants, as oxide

Arsenides —Although arsenides are amongst the commonest impurities of ores generally, ores consisting essentially of arsenides are comparatively rare The most important of them are certain double arsenides of cobalt and nickel, which in practice, however, are always contaminated with the arsenides or other compounds of foreign metals, such as iron, manganese, &c The general mode of working these ores is as follows The ore is first roasted by itself, when a part of the arsenic goes off as such and as oxide (both volatile), while a complex of lower arsenides remains This residue is now subjected to careful oxidizing fusion in the presence of glass or some other fusible solvent for metallic bases The effect is that the several metals are oxidized away and pass into the slag (as silicates) in the following order,—first the manganese, secondly the iron, thirdly the cobalt, lastly (and very slowly) the nickel , and at any stage the as yet unoxidized residue of arsenide assumes the form of a fused regulus, which sinks down through the slag as a "speis.' (This term, as will readily be understood, has the same meaning in reference to arsenides as 'mat has in regard to sulphides) By stopping the process at the right moment, we can produce a speis which contains only cobalt and nickel, and if at this stage also the flux is renewed we can further produce a speis which contains only nickel and a slag which substantially is one of cobalt only The composition of the speises generally varies from $AsMe_{3/2}$ to $AsMe_2$, where "Me" means one atomic weight of metal in toto, so that in general $1Me = xFe + yCo + zNi$, where $x + y + z = 1$ The siliceous cobalt is utilized as a blue pigment called "smalte", the nickel speis is worked up for metal, preferably by wet processes.

Minor Reagents —Besides the oxidizing and reducing agents naturally present in the fire, and the "fluxes" added for the production of slags, there are various minor reagents , of which the more important may be noticed here One—namely, metallic iron as a desulphurizer —has already been referred to

Oxide of lead PbO (litharge) is largely used as an oxidizing agent At a red heat, when it melts, it readily attacks all metals except silver and gold, the general result being the formation of a mixed oxide and of a mixed regulus, a distribution, in other words, of both the lead and the metal acted on between slag and regulus More important and more largely utilized is its action on metallic sulphides, which, in general, results in the formation of three things besides sulphurous acid gas, viz , a mixed oxide slag including the excess of litharge, a regulus of lead (which may include bismuth and other more readily reducible metals), and, if the litharge is not sufficient for a complete oxidation, a "mat" comprising the more readily sulphurizable metals Oxide of lead, being a most powerful solvent for metallic oxides generally, is also largely used for the separation of silver or gold from base metallic oxid..

---

[1] Examples are given in GOLD and COPPER See also SILVER

Metallic lead is to metals generally what oxide of lead is to metallic oxides It accordingly is available as a solvent for so to say licking up small particles of metal diffused throughout a mass of slag or other dross and uniting them into one regulus This naturally leads us to consider the process of "cupellation, which discounts the solvent powers of both metallic lead and its oxide This process serves for the extraction of gold and silver from their *alloys with base metals such as copper, antimony, &c* The first step is to fuse up the alloy with a certain proportion of lead, which is determined by the weight of base metal to be eliminated, and is always sufficient to produce a lead alloy of low fusing point This alloy is heated on a shallow dish shaped bed of bone earth to red ness, and at this temperature subjected to the action of air The base metals (copper, &c) are oxidized away, the first portions as an infusible scum containing little oxide of lead, the latter in the form of a solution in molten litharge Lead is in general, less oxidizable than the other base metals, hence the last instalment of liquid litharge which runs off is pure, and the ultimately remaining regulus consists of silver and gold only These latter may be separated by nitric acid or boiling oil of vitriol, which converts the silver into soluble salts and leaves the gold

Oxide of iron, and also binoxide of manganese, are used for the decarburation of pig iron The oxygen of the reagent burns the carbon of the pig into carbonic acid, while the metal of the reagent becomes iron and FeO or MnO respectively, the oxides uniting with the silica added as such, or formed by the oxidation of the silicon of the pig, into a fusible slag

Iron pyrites, FeS_2, is employed for the preliminary concentration of traces of gold diffused throughout slags or base ores The reagent, through the action of the heat, gives up one half of its sulphur, which reduces part of the metallic oxides present The gold and silver unite with what is left of protosulphide of iron (FeS) into a mat, which is then worked up for the noble metals

Fluxes —Practically speaking, all ores are contaminated with more or less of gangue, which in general consists of infusible matter, and consequently, if left unheeded in the reduction of the metallic part of the ore, would retain more or less of the metal disseminated through it, or at best foul the furnace To avoid this, *the ore as it goes into the furnace is mixed with* "fluxes so selected as to convert the gangue into a fusible "slag, which readily runs down through the fuel with the regulus and separates from the latter The quality and proportion of flux should, if possible, be so chosen that the formation of the slag sets in only after *the metal has been reduced and molten , or else part of the basic* oxide of the metal to be extracted may be dissolved by the slag and its reduction thus be prevented or retarded Slags are not, as one might be inclined to think, a necessary evil if an ore were free from gangue we should add gangue and flux from without to produce a slag, because one of its functions is to form a layer on the regulus which protects it against the further action of the blast or furnace gases Fluxes may be arranged under the three heads of (1) fluor spar (which is *sui generis*), (2) basic fluxes and (3) acid fluxes

Fluor spar owes its name to the facility with which it fuses up at a red heat with silica sulphates of lime and barium, and a few other infusible substances into homogeneous masses It shows little tendency to dissolve basic oxides, such as lime, &c One part of fluor spar liquefies about half a part of silica, four parts of sulphate of lime, and one and a half parts of sulphate of baryt^ Upon these facts its wide application in metallurgy is founded

Carbonate of soda (or potash) may be said to be the most powerful of basic fluxes It dissolves silica and all silicates into fusible glasses On the other hand, borax may be taken as a type for the acid fluxes At a red heat when it forms a viscid fluid, it readily dissolves up all basic oxides into fusible complex borates Now the gangue of an ore in general consists either of some basic material such as carbonate of lime (or magnesia), ferric oxide, alumina, &c , or of silica (quartz) or some more or less acid silicate, or else of a mixture of the two classes of bodies So any kind of gangue might be liquefied by means of borax or by means of alkaline carbonate , but neither of the two is used otherwise than for assaying , what the practical metal smelter does is to add to a basic gangue the proportion of silica, and to an acid ore the proportion of lime, or, indirectly, of ferrous or perhaps manganous oxide, which it may need for the formation of a slag of the proper qualities The slag must possess the proper degree of saturation In other words, taking SiO_2+nMeO (where MeO means an equivalent of base) as a formula for the potential slag, n must have the proper value If n is too small, *i e*, if the slag is too acid it may dissolve up part of the metal to be brought out as a silicate , if n is too great, *i e* , the slag too basic, it may refuse to dissolve, for instance, the ferrous oxide which is meant to go into it, and this oxide will then be reduced, and its metal (iron in our example) contaminate the regulus In reference to the problem under discussion, it is worth noting that oxides of lead and copper are more readily reduced to metals than oxide of iron Fe_2O_3 is to FeO, the latter more readily to FeO than FeO itself to metal, and FeO more readily to metal than manganous oxide is Oxide of calcium (lime) is not reducible at all The order of basicity in the oxides (their readiness to go into the slag) is precisely the reverse

Most slags being, as we have seen complex silicates, it is a most important problem of scientific metallurgy to determine the relations in this class of bodies between chemical composition on the one hand and fusibility and solvent power for certain oxides (CaO, FeO, SiO, &c) on the other Now the composition of a silicate can be *stated in an infinite number of ways , but there must be one* mode of formulation which reduces the law to its simplest terms The mode adapted by metallurgists is something like the following If we start with the quantity H_2Cl_2 of muriatic acid or the quantity H_2SO_4 of sulphuric acid, it is clear that to convert either into a normal salt we require such a quantity of base as will convert the H_2 of the acid completely into water, but the quantity of base that does so is that containing one atomic weight of oxygen Hence it is reasonable to define the quantities K_2O of potash,[1] Na_2O of soda,[1] CaO of lime, MgO of magnesia, FeO of ferrous oxide, $\frac{1}{3}Al_2O_3(=alO)$ of alumina, $\frac{1}{3}Fe_2O_3(=feO)$ of ferric oxide, as representing each "one equivalent' of base also in reference to silica, although silica has a characteristically indefinite basicity Most slags are alloys or compounds of silicates of Al_2O_3 or Fe_2O_3, and of silicates of protoxides (CaO, &c), hence their general composition is

$$n(RO+xSiO_2)+m[(fe\text{ or }al)O+xSiO_2]$$

This introduction will enable the reader to understand the following mode of classifying and naming composition in silicates

Name	Formula	Oxygen Ratio		x
		Base	Acid	
I Singulo silicates	$\frac{1}{2}SiO_2+1MO$	1	1	$\frac{1}{2}$
II Bi silicates	$1SiO_2+1MO$	1	2	1
III Tri silicates	$\frac{3}{2}SiO_2+1MO$	1	3	$\frac{3}{2}$

The names are the metallurgic ones , scientific chemists designate Class I as orthosilicates, Class II as metasilicates, Class III as sesqui silicates In the formulæ M stands for K_2, Ca, Fe, &c , or for al $=\frac{2}{3}$Al, fe $=\frac{2}{3}$Fe &c , or, shortly, MO for one equivalent of base as above defined It should be possible to represent each quality of a silicate as a function of x, $\frac{n}{m}$, and of the nature of the individual bases that make up the RO and (fe or al) O respectively Our actual knowledge falls far short of this possibility The problem, in fact, is a very tough one, the more so as it is complicated by the existence of aluminates, compounds such as Al_2O_3 3CaO, in which the alumina plays the part of acid, and the occasional existence of compounds of fluorides and silicates in certain slags The following notes on the fusibility of simple silicates are taken from Plattner s researches

Of the lime silicates, the tri silicate melts at 2100° C , the bi silicate at 2150°

Magnesia silicates are most refractory The bi silicate and tri silicate melt in the oxyhydrogen flame at 2250°

Of manganous silicates, the easily fusible bi silicate is yellow or red , the tri silicate is more refractory

Of cuprous (Cu_2O) silicates, the bi silicate is violet, and melts pretty easily, the singulo silicate is red, dense, and rather refractory

Cupric silicates, as slags, hardly exist,—the CuO being always reduced to at least Cu_2O

Lead silicates all melt readily into yellowish transparent glasses But they have no standing as slags

As regards the ferrous silicates, the singulo silicate (orthosilicate) fuses at 1790° (this is about the composition of iron puddling slag), the bi silicate is less readily fusible

Ferric silicates (unmixed) do not exist as slags,—the Fe_2O_3 being reduced in the fire to 1FeO, although Fe_2O_3 occasionally replaces part of the Al_2O_3 in complex silicates

Alumina silicates are all infusible in even the hottest furnace fires They begin to soften in the oxyhydrogen flame at about 2400° But certain aluminates, for instance the salt 3 CaO $1Al_2O_3$ according to Sefstrom, melt at furnace heats

The fusing points of mixtures of two simple silicates cannot be calculated from those of the components In many cases it is lower than either of the latter two Thus for instance most magnesia lime silicates fuse,—the bi silicate combination (Mg, Ca)$OSiO_2$ most readily

Alumina silicates become fusible by addition of a sufficient proportion of silicate of lime at about 1918° The singulo silicate and bi silicate combinations melt into grey glasses Magnesia acts like lime, and so, in a more limited sense, do ferrous and manganous oxides , but their double compounds with Al_2O_3 and silica are more viscid when fused

Plattner's work is a bold attempt to deal synthetically with the problem here presented, but it does not go the length of even an approximate solution No one seems to have done much to continue it, hence in the meantime the metallurgist has, for his guidance, to rely on the very numerous analyses which have been made of slags actually produced (by the rule of thumb) in successful metallurgical operations For some of such slags also Plattner has determined the fusing points He found for (1) Freiberg lead slag, $9RO$, $3alO$, $8SiO_2$, oxygen ratio, 3 4, melting point at 1317° C, (2) Freiberg crude slag, $15RO$, $3alO$, $18SiO_2$, oxygen ratio, 1 1, melting point at 1331° C, (3) Freiberg black copper slag, $24FeO$, Al_2O_3, $15SiO_2$, oxygen ratio, 9 10, melting point at 1338° C, (4) High furnace slag, $6CaO$, $3alO$, $9SiO_2$, oxygen ratio, 1 1 melting point at 1431° C[1]

---

[1] Few slags contain more than traces of alkalies.

Metallurgic Assaying—To assay an ore originally meant to execute a set of tentative experiments on a small scale in order to find out the proper mode of working it practically But nowadays the term is always used in the sense of an analysis carried out to determine the money value of an ore For this purpose, in many cases it is sufficient to determine the percentages of the metals for which the ore is meant to be worked But sometimes nothing short of a complete analysis will do This holds more especially of ores of iron As this metal is cheap the value of an ore containing it depends as much on the nature and relative quantities of the impurities as on the percentage of metal The proved absence of sulphur and phosphorus may be worth more than an additional 5 per cent of iron, which latter again would perhaps not compensate for the proved presence of a large percentage of uncombined silica

An assay to be of any value must start with a fair sample of the object of sale The fulfilment of this condition in all cases is difficult The general method is, from say a given ship load of ore, to take out (say) half a ton of ore from a large number of different places and to crush this large sample into small fragments of uniform size, which are well shovelled up together From different parts of this ore heap a sample of the second order—amounting to, say, 20 ℔—is then drawn, and rendered more homogeneous by finer powdering and mixing From this sample of the second (or perhaps from one of the third) order quantities of 1 or 2 ℔ are bottled up for assaying At the same time the moisture of the ore is determined, on a large scale, by some conventional method such as the drying of 1 or 2 ℔ in an open basin at 100° C, and weighing of the residue as dry ore This is done at the sampling place by the firms concerned The assayer further pounds up and mixes his sample, and then proceeds to determine the percentages of moisture and metal in his own way He has always the choice between two methods the dry and the wet For the majority of gold or silver ores, and for cobalt and nickel ores almost as a rule, certain dry process tests are preferred as the most exact analytically In almost all other cases it may be said that the wet method is susceptible of the higher degree of precision, yet even in some of these cases the old dry process tests are preferred to the present day For instance all copper ores in the British Isles are sold by the result of the Swansea assay, a kind of imitation of the process of sulphureous copper ore smelting, and this singularly, is adhered to even in the case of such cupriferous materials as are worked by the wet way, although the Swansea assay is well known to lose about 1 per cent of the copper present A copper smelter therefore had better buy 5 per cent than 10 per cent copper pyrites cinders because in the first case he pays only for four fifths, while in the latter he must pay for nine tenths of the copper present. To compensate for this anomaly, empirical methods have been contrived for calculating prices (W D)

METALS The earliest evidence of a knowledge and use of metals is found in the prehistoric implements of the so-called Bronze and Iron ages In the earliest periods of written history, however, we meet with a number of metals in addition to these two The Old Testament mentions six metals—gold, silver, copper, iron, tin, and lead The Greeks, in addition to these and to bronze, came also to know mercury, and the same set of metals, without additions, forms the list of the Arabian chemists of the 8th and of the Western chemists of the 13th century During the 15th century Basilius Valentinus discovered antimony, he also speaks of zinc and bismuth, but their individuality was established only at a later period About 1730–40 the Swede Brand discovered arsenic and cobalt (the former is not reckoned a metal by modern chemists), while the Englishman Ward recognized the individuality of platinum Nickel was discovered in 1774 by Cronstedt, manganese in 1774 by Scheele The brothers D'Elhujart, in 1783, prepared tungsten, Hjelm, in 1782, isolated molybdenum from molybdic oxide, where its existence had been conjecturally asserted by Bergmann in 1781 Uranium, as a new element, was discovered by Klaproth in 1789, but his metallic "uranium," after having been accepted as a metal by all chemists until 1841, was then recognized as an oxide by Péligot, who subsequently isolated the true metal Tellurium was discovered by Muller von Reichenbach in 1782 (again by Klaproth in 1798), titanium, by Klaproth in 1795, chromium, by Vauquelin in 1797, tantalum, by Hatchett in 1801, and by Ekeberg in 1802 Palladium, rhodium, iridium, and osmium (which four metals always accompany platinum in its ores) were discovered, the first two by Wollaston in 1803, the other two by a number of chemists, but their peculiarity was established chiefly by Smithson Tennant

After Davy, in 1807 and 1808, had recognized the alkalies and alkaline earths as metallic oxides, the existence of metals in all basic earths became a foregone conclusion, which was verified sooner or later in all cases But the discovery of aluminium by Wohler in 1828, and that of magnesium by Bussy in 1829, claim special mention Cadmium, a by no means rare heavy metal, was discovered only in 1818, by Stromeyer

Of the large number of discoveries of rare metals which have been made in more recent times only a few can be mentioned, as marking new departures in research or offering other special points of interest In 1861 Bunsen and Kirchhoff, by means of the method of spectrum analysis, which they had worked out shortly before, discovered two new alkali metals which they called cæsium and rubidium. By means of the same method Crookes, in 1861, discovered thallium, Reich and Richter, in 1863, indium, and Lecoq de Boisbaudran, in 1875, gallium The existence of the last-named metal had been maintained, theoretically, by Mendelejeff, as early as 1871 The existence of vanadium was proved in 1830 by Sefstrom, but what he, and subsequently Berzelius, looked upon as the element was, in 1867, proved to be really an oxide by Roscoe, who also succeeded in isolating the true metal

The development of earlier notions on the constitution of metals and their genetic relation to one another forms the most interesting chapter in the history of chemistry (see ALCHEMY) What modern science has to say on the matter is easily stated all metals properly so called (i e, all metals not alloys) are elementary substances, hence, chemically speaking, they are not "constituted" at all, and no two can be related to each other genetically in any way whatever Our scientific instinct shrinks from embracing this proposition as final, but in the meantime it must be accepted as correctly formulating our ignorance on the subject All metallic elements agree in this that they form each at least one basic oxide, or, what comes to the same thing, one chloride, stable in opposition to liquid water This at once suggests an obvious definition of metals as a class of substances, but the definition would be highly artificial and objectionable on principle, because when we speak of metals we think, not of their accidental chemical relations, but of a certain sum of mechanical and physical properties which unites them all into one natural family What these properties are we shall now endeavour to explain

All metals, when exposed in an inert atmosphere to a sufficient temperature, assume the form of liquids, which all present the following characteristic properties They are (at least practically) non transparent, they reflect light in a peculiar manner, producing what is called "metallic lustre" When kept in non metallic vessels they take the shape of a convex meniscus. These liquids, when exposed to higher temperatures, some sooner others later, pass into vapours What these vapours are like is not known in many cases, since, as a rule, they can be produced only at very high temperatures, precluding the use of transparent vessels Silver vapour is blue, potassium vapour is green, many others (mercury vapour, for instance) are colourless The liquid metals, when cooled down sufficiently, some at lower others at higher temperatures, freeze into compact solids, endowed with the (relative) non transparency and the lustre of their liquids These frozen metals in general form compact masses consisting of aggregates of crystals belonging to the regular or rhombic or (more rarely) the quadratic system But in many cases the crystals are so closely packed as to produce an apparent absence of all structure Compared with non metallic solids, they in general are good conductors of heat and of electricity But their most characteristic, though not perhaps their most general, property is that they combine in themselves the apparently incompatible properties of elasticity and rigidity on the one hand and plasticity on the other To this remarkable combination of properties more than to anything else the ordinary metals owe their wide application in the mechanical arts In former times a high specific gravity used to be quoted as one of the characters of the genus, but this no longer holds, since we have come to know of a whole series of metals which float on water Let us now proceed to see to what degree the mechanical and physical properties of the genus are developed in the several individual metals

---

[1] For further information on slags, see Berthier, *Traité des essais par la voie sèche*, Winkler, *Erfahrungssätze uber die Bildung der Schlacken*, Freiberg, 1827, Plattner, *Vorlesungen uber allgemeine Hüttenkunde*, i 28 *sq*, Percy, *Metallurgy*

Non Transparency —This, in the case of even the solid metals, is perhaps only a very low degree of transparency In regard to gold this has been proved to be so, gold leaf, or thin films of gold produced chemically on glass plates, transmit light with a green colour On the other hand, those infinitely thin films of silver which can be produced chemically on glass surfaces are absolutely opaque Very thin films of liquid mercury, according to Melsens, transmit light with a violet blue colour, also thin films of copper are said to be translucent Other metals, so far as we know, have not been more exactly investigated in this direction

Colour —Gold is yellow, copper is red, silver, tin, and some others are pure white, the majority exhibit some modification or other of grey

Reflexion of Light —Polished metallic surfaces, like those of other solids, divide any incident ray into two parts, of which one is refracted while the other is reflected,—with this difference, however, that the former is completely absorbed, and that the latter, in regard to polarization, is quite differently affected[1] The degree of absorption is different for different metals According to Jamin, the remaining intensity, after one and ten successive perpendicular reflexions respectively from the metal mirrors named, is as follows (original intensity = 1) —

	Silver		Speculum Metal		Steel	
	1 R	10 R	1 R	10 R	1 R	10 R
Red	929	478	692	035	609	007
Yellow	905	339	632	010	599	006
Violet	867	242	599	006	599	006

This shows the great superiority of silver as a reflecting medium, especially in the case of repeated reflexion

Crystalline Form —Most (perhaps all) metals are capable of crystallization, and in most cases isolated crystals can be produced by judiciously managed partial freezing The crystals belong to the following systems —*regular system* —silver, gold, palladium, mercury, copper, iron, lead, *quadratic system*—tin, potassium, *rhombic system*—antimony, bismuth, tellurium, zinc, magnesium

Structure —Perhaps all metals, in the shape which they assume in freezing, are crystalline, only the degree of visibility of the crystalline arrangement is very different in different metals, and even in the same metal varies according to the slowness of solidification and other circumstances

Of the ordinary metals, antimony, bismuth, and zinc may be mentioned as exhibiting a very distinct crystalline structure a bar shaped ingot readily breaks, and the crystal faces are distinctly visible on the fracture Tin also is crystalline a thin bar, when bent, "creaks" audibly from the sliding of the crystal faces over one another, but the bar is not easily broken, and exhibits an apparently non-crystalline fracture —Class I

Gold, silver, copper, lead, aluminium, cadmium, iron (pure), nickel, and cobalt are practically amorphous, the crystals (where they exist) being so closely packed as to produce a virtually homogeneous mass —Class II

The great contrast in apparent structure between cooled ingots of Class I and of Class II appears, however, to be owing chiefly to the fact that, while the latter crystallize in the regular system, metals of Class I form rhombic or quadratic crystals Regular crystals expand equally in all directions, rhombic and quadratic ores expand differently in different directions Hence, supposing the crystals immediately after their formation to be in absolute contact with one another all round, then, in the case of Class II, such contact will be maintained on cooling, while in the case of Class I the contraction along a given straight line will in general have different values in any two neighbouring crystals, and the crystals consequently become, however slightly, detached from one another The crystalline structure which exists on both sides becomes visible only in the metals of the first class, and only there manifests itself as brittleness

Closely related to the structure of metals is their degree of "plasticity' (susceptibility of being constrained into new forms without breach of continuity) This term of course includes as special cases the qualities of "malleability" (capability of being flattened out under the hammer) and "ductility ' (capability of being drawn into wire), but it is well at once to point out that these two special qualities do not always go parallel to each other, for this reason amongst others that ductility in a higher degree than malleability is determined by the tenacity of a metal Hence tin and lead, though very malleable, are little ductile The quality of plasticity is developed to very different degrees in different metals, and even in the same species it depends on temperature, and may be modified by mechanical or physical operations A bar of zinc, for instance, as obtained by casting, is very brittle, but when heated to 100° or 150° C it becomes sufficiently plastic to be rolled into the thinnest sheet or to be drawn into wire Such sheet or wire then remains flexible after cooling, the originally only loosely cohering crystals having got intertwisted and forced into absolute contact with one another,—an explanation supported by the fact that rolled zinc has a somewhat higher specific gravity (7 2) than the original ingot (6 9) The same metal, when heated to 205° C, becomes so brittle that it can be powdered in a mortar Pure iron, copper, silver, and other metals are easily drawn into wire, or rolled into sheet, or flattened under the hammer But all these operations render the metals harder, and detract from their plasticity Their original softness can be restored to them by "annealing," *i e*, by heating them to redness and then quenching them in cold water In the case of iron, however, this applies only if the metal is perfectly pure If it contains a few parts of carbon per thousand, the annealing process, instead of softening the metal, gives it a "temper," meaning a higher degree of hardness and elasticity (see below)

What we have called plasticity must not be mixed up with the notion of softness, which means the degree of facility with which the plasticity of a metal can be discounted Thus lead is far softer than silver, and yet the latter is by far the more plastic of the two The now famous experiments of Tresca (*Comptes Rendus*, lix 754) show that the plasticity of certain metals at least goes considerably farther than had before been supposed He operated with lead, copper, silver, iron, and some other metals Round disks made of these substances were placed in a closely fitting cylindrical cavity drilled in a block of steel, the cavity having a circular aperture of two or four centimetres below By means of an hydraulic press, applied to a superimposed piston, a pressure of 100,000 kilos was made to act upon the disks, when the metal was seen to "flow out of the hole like a viscid liquid In spite of the immense rearrangement of parts there was no breach of continuity What came out below was a compact cylinder with a rounded bottom, consisting of so many layers superimposed upon one another Parallel experiments with layers of dough or sand plus some connecting material proved that the particles in all cases moved along the same tracks as would be followed by a flowing cylinder of liquid Of the better known metals potassium and sodium are the softest, they can be kneaded between the fingers like wax After these follow first thallium and then lead, the latter being the softest of the metals used in the arts Among these the softness decreases in about the following order —lead, pure silver, pure gold, tin, copper, aluminium, platinum, pure iron As liquidity might be looked upon as the *ne plus ultra* of softness, this is the right place for stating that, while most metals, when heated up to their melting points, pass pretty abruptly from the solid to the liquid state, platinum and iron first assume, and throughout a long range of temperatures retain, a condition of viscous semi solidity which enables two pieces of them to be "welded together by pressure into one continuous mass Potassium and sodium might probably be welded if their surfaces could be kept clear of oxide

---

[1] This may be the cause of the peculiarity of metallic lustre

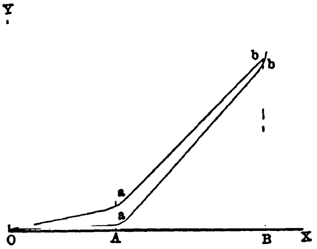
According to Prechtl, the ordinary metals, in regard to the degree of facility or perfection with which they can be hammered flat on the anvil, rolled out into sheet, or drawn into wire, form the following descending series —

Hammering	*Rolling into Sheet*	*Drawing into Wire*
Lead	Gold	Platinum
Tin	Silver	Silver
Gold	Copper	Iron
Zinc	Tin	Copper
Silver	Lead	Gold
Copper	Zinc	Zinc
Platinum	Platinum	Tin
Iron	Iron	Lead

To give an idea of what can be done in this way, it may be stated that gold can be beaten out to leaf of the thickness of $\frac{1}{3800}$ mm, and that platinum, by judicious work, can be drawn into wire $\frac{1}{20000}$ mm thick

By the hardness of a metal we mean the resistance which it offers to the file or to the engraver s tool Taking it in this sense, it does not necessarily measure, *e g*, the resistance of a metal to abrasion by friction Thus, for instance, 10 per cent aluminium bronze is scratched by an edge tool made of ordinary steel as used for knife blades And yet it has been found that the sets of needles used for perforating postage stamps last longer if made of aluminium bronze than they do if made of steel

Elasticity —All metals are elastic to this extent that a change of form brought about by stresses not exceeding certain limit values, will disappear on the stress being removed Strains exceeding the "limit of elasticity result in permanent deformation or (if sufficiently great) in rupture Where this limit lies is in no case precisely known According to Wertheim[1] (who has done more for our knowledge of the subject than any one else) and Hodgkinson, the real law seems to be pretty much as indicated by the two curves on the accompanying diagram, where in reference to a metallic wire, stretched by an appended weight, the abscissa always means the numerical value P of the weight, the ordinate of the upper curve the total elongation caused by P, the ordinate of the lower curve that part of the elongation which remains when P is removed, so that the piece of the ordinate between the two curves gives the temporary ("elastic) expansion From P=0 up to a somewhat indefinite point (*a* or A) both curves are nearly straight lines, the lower almost coinciding in its beginning with the axis of abscissæ from that point onwards these two curves approach each other and at a short distance from the point of rupture they rapidly converge towards intersection For any value of P which lies fairly on the safe side of A, we have approximately



$$\lambda = \frac{lP}{q}\epsilon,$$

where λ means the elastic (or substantially the total) expansion, *l* the length and *q* the square section of the wire or cylindrical bar operated upon The reciprocal of ϵ (viz E=1/ϵ) is called the modulus of elasticity

Wertheim has determined this constant for a large number of metals and alloys He used three methods one was to measure the elongations produced in a wire of given dimensions by a succession of charges the other two consisted in causing a measured bar to give off a musical note by (*a*) longitudinal and (*b*) transversal vibration and counting the vibrations per second The following table gives some of his results Column 2 gives the constant E for millimetre and kilogramme Hence 1000/E is the elongation in millimetres per metre length per kilo Column 3 shows the charge causing a permanent elongation of 0 05 mm per metre,—which, for practical purposes, he takes as giving the limit of elasticity, column 4 gives the breaking strain Values of E in square brackets [ ] are derived from vibration experiments the rest from direct measurements of elongations Numbers in round brackets ( ) do not necessarily refer to the same specimen as the

Name	E	For Wire of 1 Square mm Section Weight (in kilos) causing	
		Permanent Elongation of $\frac{1}{10000}$	Breakage
Lead drawn	1 803	0 25	2 1
annealed	1 2	0 20	1 8
Tin drawn	[3 973]	0 45	(2 45)
annealed	[4 060]	0 20	
Cadmium drawn	[5 5]		2 74
annealed	[4 7]		
Gold drawn	8 132	13 5	27
annealed	5 585	3 0	10
Silver drawn	358	11 3	29
annealed	141	2 6	16
Zinc pure cast in mould	9 021		
Zinc ordinary drawn	8 35	0 5	13
annealed	[9 467]	1 00	
Palladium drawn	11 59	16	
annealed	9 89	under 5	27
Copper drawn	12 449	1	40
annealed	10 519	under 3	30
Platinum wire medium thickness drawn	17 004	(26)	
annealed	15 518	(14)	
Platinum wire thick drawn	15 987		34
annealed	15 6 2		23
Iron[2] drawn	20 869	32	61
[2] annealed	20 794	under 5	47
Nickel[3] drawn			[illegible]×61
Cobalt[3]			2×61
Aluminium[4]	7 040		
Aluminium bronze[4]	10 700		
Brass[5]	8 543		
German silver[6]	10 788		

The above numbers may be assumed to hold for temperatures from 15° to 20° C Wertheim executed determinations also at other temperatures but, as his numbers do not appear to reveal the true relations between E and temperature, we quote the results of Kohlrausch and Loomis who found the following relations between the modulus E_0 for 0° C and the value E_t for $+t°$ C —

---

[1] *Annales de Chimie et de Physique* [iii] vol xli

[2] From Du Brery

[3] Approximate by H St Clair Deville

[4] From deflexion of hammered bar of 5 mm thickness charged in the middle determined by W Dittmar

[5] Composition $ZnCu_2$ (Wertheim)

[6] Composition $Zn_4Cu_{13}Ni_8$ (Wertheim)

$$\text{Iron}\quad E_t = E_0(1\ \ 000483\,t - 00000012\,t^2)$$
$$\text{Copper}\quad E_t = E_0(1 - 000572\,t - 00000028\,t^2)$$
$$\text{Brass}\quad E_t\ \ E_0(1 - 000485\,t - 00000136\,t^2)$$

Thus, for these three metals at least, the value of E diminishes, when temperature increases, at pretty much the same rate per degree of temperature

Specific Gravity —This varies in metals from 594 (lithium) to 22 48 (osmium), and in one and the same species is a function of temperature and of previous physical and mechanical treatment It has in general one value for the powdery metal as obtained by reduction of the oxide in hydrogen below the melting point of the metal, another for the metal in the state which it assumes spontaneously on freezing and this latter value again, in general, is modified by hammering, rolling, or wire drawing &c These mechanical operations do not necessarily add to the density stamping it is true, does so necessarily, but rolling or drawing occasionally causes a diminution of the density Thus for instance chemically pure iron in the ingot has the specific gravity 7 844, when it is rolled out into thin sheet the value falls to 7 6 when drawn into thin wire to 7 75 (Berzelius) The following table gives the specific gravities of all metals (except a few very rare ones) according to the most trustworthy modern determinations Where special statements are not made the numbers may be assumed to hold for the ordinary temperature (15° to 17° or 20° C) referred to water of the same temperature (specific gravity = 1) as a standard and to hold for the natural frozen metal.

Name of Metal	Specific Gravity	Authority
Lithium	594	Bunsen
Potassium	875	Baumhauer
Sodium	9735	
Rubidium	1 52	Bunsen
Calcium	1 578	Bunsen and Matthiesen
Magnesium	1 743	Bunsen
Cæsium	1 88	Setterberg
Beryllium	2 1	Debray
Strontium	2 5	
Aluminium pure ingot	2 583 at 4	Mallet 1880
Aluminium ordinary hammered	2 67	
Barium	over 4	Clarke
Zirconium	4 15	Troost
Vanadium powder	5	Roscoe
Gallium	9	Lecoq de Boisbaudran
Lanthanum	6 163	
Didymium	6 544	Hillebrandt and Norton
Cerium	6 728	
Antimony	6 715 at 16	Marchand and Scheerer
Chromium	6 81	Wohler
Zinc, ingot	6 915	Karsten
rolled out	7 2	
Manganese	7 14 to 7 2	Brunner
Tin cast	29 to 7 299	Various authorities
crystallized by galvanic current from solutions	7 178	W H Miller
Indium	7 42	Richter
Iron chemically pure ingot	844	Berzelius
thin sheet	6	
wrought high quality	8 to 9	
Nickel ingot	8 279	Richter
forged	8 666	
Cadmium ingot	8 546	Schroder
hammered	8 667	
Cobalt	8 5 to 8 7	
Molybdenum containing 4 to 5 per cent of carbon	8 6	Debray
Copper native	8 94	
cast	8 92	Marchand and Scheerer
wire or thin sheet	8 94 to 8 95	
electrotype pure	8 945	Hampe
Bismuth	9 823 at 12	Holzmann
Silver cast	10 4 to 10 5	
stamped	10 57	G Rose
Lead very slowly frozen	11 254	Deville
quickly frozen in cold water	11 363	
Palladium	11 4 at 22 5	Deville and Debray
Thallium	11 86	Crookes
Rhodium	12 1	Bunsen
Ruthenium	12 26 at 0	Deville and Debray
Mercury liquid	13 595 at 0	H Kopp
„ solid	14 39 below −40	
Tungsten compact by H_2 from chloride vapour	16 54	Wohler 1855
as reduced by hydrogen powder	19 13	Roscoe
Uranium	18 33	Péligot 1868
Gold ingot	19 265 at 13°	Matthiesen
stamped	19 31 to 19 34	G Rose
powder precipitated by ferrous sulphate	19 55 to 19 [illegible]	
Platinum pure	21 46	
Iridium	22 40	
Osmium	22 477	Deville and Debray 1876

Thermic Properties —The specific heats of most metals have been determined very carefully by Regnault The general result is that conformably with Dulong and Petit's law the atomic heats all come to very nearly the same value (of about 6 4) *i e*, atomic weight by specific heat = 6 4 Thus we have for silver by theory 6 4/108 = 0593, and by experiment 0570 for 10° to 100° C

The expansion by heat varies greatly The following table gives the linear expansions from 0° to 100° C according to Fizeau (*Comptes Rendus*, lxviii 1125), the length at 0° being taken as unity

Name of Metal	Expansion 0 to 100°
Platinum cast	000 907
Gold cast	001 451
Silver cast	001 936
Copper native from Lake Superior	001 708
Copper artificial	001 869
Iron soft as used for electromagnets	001 228
reduced by hydrogen and compressed	001 208
Cast steel English annealed	001 110
Bismuth in the direction of the axis	001 642
at right angles to axis	001 239
mean expansion calculated	001 374
Tin, of Malacca compressed powder	002 269
Lead cast	002 948
Zinc distilled compressed powder	002 905
Cadmium distilled compressed powder	003 102
Aluminium cast	002 336
Brass (71 5 per cent copper 28 5 per cent zinc)	001 879
Bronze (86 3 per cent copper 9 7 per cent tin 4 0 per cent zinc)	001 802

The coefficient of expansion is constant for such metals only as crystallize in the regular system, the others expand differently in the directions of the different axes To eliminate this source of uncertainty these metals were employed as compressed powders The cubical expansion of mercury from 0° to 100° C is 018153 $= \frac{1}{55\ 087}$ (Regnault)

Fusibility and Volatility —The fusibility in different metals is very different, as shown by the following table, which, besides including all the fusing points (in degrees C) of metals which have been determined numerically, indicates those of a selection of other metals by the positions assigned to them in the table Of the temperatures given those above (say) 500° C must be looked upon as rough approximations

Name of Metal	Fusing Point	Authority
Mercury	−38 8	B Stewart
Cæsium	+26 to 27	Setterberg
Gallium	30 1	L de Boisbaudran
Rubidium	38 5	Bunsen
Potassium	62 5	
Sodium	95 5	
Lithium	180 0	?
Indium	176	Richter(?)
Tin	228	Rudberg
Bismuth	264	
Thallium	290	Lamy
Cadmium	320	Rudberg
Lead	325	
Antimony	425	
Zinc	415	Person
	412	Daniell.
Incipient Red Heat	525	Pouillet
Magnesium		
Aluminium		
Cherry Red Heat	700	Pouillet
Silver	1 040	Becquerel
Gold	1 100	
Yellow Heat	1 100	Pouillet
Copper	1 200	
Iron wrought	1 300 to 1 400	
chemically pure	higher	
Cobalt	1 400	
Nickel	1 600	
Uranium	?	
Dazzling White Heat	1 500 to 1 600	Pouillet
Palladium is barely fusible at the highest wind furnace heat The following melt only in the oxyhydrogen flame —		
Platinum	2 000	
Iridium		
Rhodium		
Ruthenium		
Max Temp of Oxyhydrogen Flame	2 870	Bunsen[1]
Osmium does not melt at 2 870 *i e* is as yet infusible		

Of the volatility of metals we have little precise knowledge, only the following boiling points are known numerically —

Name of Metal.	Boiling Point	Authority
Mercury	357 3	Regnault
Cadmium	860	Deville and Troost
Zinc	1 040	
Potassium	below 1 040	Dewar and Dittmar
Sodium	above 1 040	

For practical purposes the volatility of metals may be stated as follows —

1 Distillable below redness mercury

2 Distillable at red heats cadmium, alkali metals, zinc, magnesium

3 Volatilized more or less readily when heated beyond their fusing points in open crucibles antimony (very readily), lead, bismuth, tin, silver

---

[1] *Jahresb f Chem.*, 1867 p 41 *Phil Mag* xxxiv [illegible]

4. Barely so gold, (copper)

5 Practically non volatile (copper), iron, nickel, cobalt, aluminium, also lithium, barium, strontium, and calcium

In the oxyhydrogen flame silver boils, forming a blue vapour, while platinum volatilizes slowly, and osmium, though infusible, very readily

Latent Heats of Liquefaction—Of these we know little The following numbers are due to Person—ice, it may be stated, being 80

M tal	Latent Heat	Metal	Latent Heat
Mercury	2 82	Cadmium	13 6
Lead	5 37	Silver	21 1
Bismuth	12 4	Zinc	28 1

Of the latent heats of vaporization only that of mercury has been determined —by Marignac, who found it to be 103 to 106 units

Conductivity —Conductivity, whether thermic or electric, is very differently developed in different metals, and, as an exact knowledge of these conductivities is of great scientific and practical importance, much attention has been given to their numerical determination The following are the modes in which the two conductivities have been defined as quantities

1 *Thermic* —Imagine one side (I) of a metallic plate, D units thick, to be kept at the constant temperature t_1, the other (II) at t_2 After a sufficient time each point between I and II will be at a constant intermediate temperature, and in every unit of time a constant quantity Q of heat will pass from any circumscribed area S on I to the opposite area S on II, according to the equation

$$Q=l\frac{S(t_1-t_2)}{D}$$

l is called the (internal) conductivity of the metal the plate is made of It is, strictly speaking, a function of t_1 and t_2, but within a given small interval of temperatures it may be taken as a constant

2 *El*[illegible] —When a given constant battery is closed successively by different wires of the same sort, then, according to experience, the strength I of the current (as measured for instance by the heat equivalent of the electricity flowing through the circuit in unit of time) is in accordance with the equation

$$A/I=1+rl/s,$$

where l is the length and s the square section of the wire, while A is a constant which, for our purpose, need not be defined in regard to its physical meaning, r measures the specific resistance of the particular metal Supposing a certain silver wire on the one hand and a certain copper wire on the other, when substituted for each other, to produce currents of the same strength, we have

$$r_1l_1/s_1=r_2l_2/s_2,$$

W[illegible]e

$$r_1/r_2=s_1l_2/(s_2l_1)=k$$

where k [illegible] the computed value of the ratio on the right hand side Hence, taking r_2, the resistance of copper, as unity, we have $r_1=k$, i e, k gives us the specific resistance of silver, that of copper being taken = 1 In this relative manner resistances are usually measured, silver generally being taken as the standard of comparison Supposing the relative resistance of a metal to be R, the reciprocal 1/R is called its "electric conductivity' For the same metal R varies with the temperature, the higher temperature corresponding to the higher resistance The following table gives the electric conductivities of a number of metals as determined by Matthiesen, and the relative internal thermic conductivities of (nominally) the same metals as determined by Wiedemann and Franz, with rods about 5 mm thick, of which one end was kept at 100° C, the rest of the rod in a "vacuum' (of 5 mm tension) at 12° C Matthiesen s results, except in the two cases noted, are from his memoir in *Pogg Ann*, 1858, ciii 428

Metals	Relative Conductivities		
	Electric		Thermic
Copper commercial No 3	774	at 18 8°	
No 2	721	22 6	
chemically pure hard drawn	93[1]		
Copper			748
Gold pure	552	21 8	548
absolutely pure	73[1]	19 0	
Brass			25
Tin pure	115	21 0	154
Pianoforte wire	144	20 4	
Iron rod			101
Steel			103
Lead pure	0777	17 3	079
Platinum	105	20 7	094
German silver	0767	18 7	063
Bismuth	0119	13 8	
Aluminium	196	19 6	
Mercury	0163	22 8	
Silver pure	1 000	0	1 000

[1] Published in 1860, and declared by Matthiesen to be more exact than the old mbers

Going by Matthiesen s old numbers, we find them to agree fairly with Wiedemann and Franz's thermic conductivities, which supports an obvious and pretty generally received proposition Matthiesen s new numbers for gold and copper, however, destroy the harmony

Magnetic Properties —Iron, nickel, and cobalt are the only metals which are attracted by the magnet and can become magnets themselves But in regard to their power of retaining their magnetism none of them comes at all up to the compound metal steel See MAGNETISM

Chemical Changes

The chemical changes which metals are liable to may be classified according to the loss of metallicity involved in them We will adopt this principle and begin with the action of metals on metals, which, as experience shows, always leads to the formation of truly metallic compounds

Any two or more metals when mixed together in the liquid state unite chemically, or at least molecularly, in this sense that, although the mixture, on standing (hot), may separate into layers, each layer is a homogeneous solution or "alloy" of, in general, all the components in one another With binary combinations the following two cases may present themselves —(1) the two metals mix permanently in any proportion, or (2) either of the two metals refuses to take up more than a certain limit proportion of the other, hence a random mixture of the two metals will, in general, part into two layers,—one a solution of A in B, the other a solution of B in A The first case presents itself very frequently, it holds, for instance, for gold and silver, gold and copper, copper and silver, lead and tin, and any alloy of these two and bismuth Many other cases might be quoted A good example of the second case is lead and zinc, either of which dissolves only a very small percentage of the other. In the preparation of an alloy we need not start with the components in the liquid state, the several metals need only be heated together in the same crucible when, in general, the liquid of the more readily fusible part dissolves the more refractory components at temperatures far below their fusing points Molten lead, for instance, as many a tyro in chemical analysis has come to learn to his cost, readily runs through a platinum crucible at little more than its own fusing point

A homogeneous liquid alloy, when solidified suddenly, say by pouring it drop by drop into cold water, necessarily yields an equally homogeneous solid But it may not be so when it is allowed to freeze gradually If, in this case, we allow the process to go a certain way, and then pour off the still liquid portion, the frozen part generally presents itself in the shape of more or less distinct crystals, whether this happens or not, the rule is that its composition differs from that of the mother liquor, and consequently from that of the original alloy This phenomenon of "liquation," as it is called, is occasionally utilized in metallurgy for the approximate separation of metals from one another,[2] but in the manipulation of alloys made to be used as such it may prove very inconvenient It does so, for instance, in the case of the copper silver alloy which our coins are made of, in a large ingot of such sterling silver the core may contain as much as 0 3 per cent of silver more than the outer shell

The existence of crystallized alloys, as the phenomenon of liquation generally, strongly suggests the idea that alloys generally are mixtures, not of their elementary components, but of chemical compounds of these elements with one another, associated possibly with uncombined remnants of these This notion is strongly supported by the fact that the formation of many alloys involves an obvious evolution of heat and a decided modification in what one would presume to be the properties of the corresponding mixture The case of sodium amalgam may be quoted as a forcible illustration What goes by this name in laboratories is an alloy of two to three parts of sodium with one hundred parts of mercury, which is easily produced by forcing the two components into contact with each other by means of a mortar and pestle, when they unite, with deflagration, into an alloy which after cooling assumes the form of a grey, hard, brittle solid, although mercury is a liquid, and sodium, though a solid, is softer than wax Similar evidence of chemical action we have in the cases of brass (copper and zinc), bronze (copper and tin), aluminium bronze (copper and aluminium), and in many others that might be quoted There are indeed a good many alloys the formation of which is not accompanied by any obvious evolution of heat or any very marked change in the mean properties of the components But in the absence of all precise thermic researches on the subject we are not in a position to assert the absence of chemical action in any case Indeed our knowledge of the proximate composition of alloys is in the highest degree indefinite—we do not even know of a single composite metal which has been really proved to be an unitary compound, and hence the important problem of the relation in alloys between properties and composition must be attacked on a purely empirical basis What has been done in this direction is shortly summarized in the following paragraphs

---

[2] A good illustration is afforded by the process of Pattinson as used for concentrating the silver in argentiferous lead See LEAD

Colour —Most metals are white or grey, so are the alloys of these metals with one another Gold alloys generally exhibit something like the shade of yellow which one would expect from their composition, its amalgams however are all white not yellow Copper shows little tendency to impart its characteristic red colour to its alloys with white or grey metals Thus for instance, the silver alloy up to about 30 per cent of copper exhibits an almost pure white colour The alloys of copper with zinc (brass) or tin (bronze) are reddish yellow when the copper predominates largely As the proportion of white metal increases the colour passes successively into dark yellow, pale yellow, and ultimately into white Aluminium bronze, containing from 5 to 10 per cent of aluminium, is golden yellow

Plasticity —This quality is most highly developed in certain pure metals, notably in gold platinum silver, and copper Of platinum alloys little is known The other three, on uniting with one another substantially retain their plasticities, but the addition of any metal outside the group leads to deterioration Thus, for instance, according to Karsten copper, by being alloyed with as little as 0 6 per cent of zinc loses its capability of being forged at a red heat it cracks under the hammer Antimony or arsenic to the extent of 0 15 per cent renders it unfit for being rolled into thin sheet or drawn out into fine wire and makes it brittle in the heat, 0 1 per cent of lead prohibits its conversion into leaf

Hardness Elasticity, Tensile Strength —In reference to these qualities, we shall confine ourselves to some very striking changes for the better which the metals (1) gold, (2 silver, (3) copper suffer when alloyed with moderate proportions (10 per cent or so) of (1) copper, (2) copper (3) tin zinc or aluminium respectively Any of these five combinations leads to a considerable increase in the three qualities named, although these are by no means highly developed in the added metals most strikingly it does so in the case of aluminium bronze (copper and aluminium) which is so hard as to be very difficult to file, and is said to be equal in tensile strength to wrought iron To illustrate this we give in the following table, after Matthiesen the breaking strains of double wires, No 23 gauge, in lb avoirdupois, for certain alloys on the one hand and their components on the other

Separate Metals		*Alloys*	
Copper	25 30	Gun metal 12 per cent of tin	80 90
Tin	less than 7		
Copper	30	Standard (22 carat) gold	[illegible]
Gold	20 2		
Silver	40 45	Alloy ⅔ of silver ⅓ of platinum	75 80
Platinum	45 0		

Specific Gravity —This subject has been extensively investigated by Matthiesen, Calvert and Johnson, Kuppfer and others In discussing the results it is convenient to compare the values (S) found with the values (S_0) calculated on the assumption that the volume of the alloy is equal to the sum of the volumes of the components Let p_1, p_2, p_3 stand for the relative weights of the components P for their joint weight, $S_1, S_2\ S_3$ for their specific gravities, and we have

$$\frac{P}{S_0}=\frac{p_1}{S_1}$$

where the expression on the right hand obviously means the conjoint volume V_0 of the components, but the actual volume of the alloy formed by their union is, in general, $V=V_0(1+e)$, where e means the expansion (or, when negative, the contraction) of unit-volume of mixture. Hence the real value

$$S=S_0/(1+e),$$

whence

$$e=(S_0-S)/S$$

Matthiesen's investigation (*Pogg Annalen* for 1860, vol cx p 21) extends over a large number of binary alloys derived from the metals named in the following table He naturally began by procuring pure specimens of these metals and determining their specific gravities The results (each the mean of a number of determinations) were as follows —

Name	Specific Gravity S at t° C	t	Adopted Atomic Weight
Antimony	6 718	14 8°	122 3
Tin	7 294	12 8	118
Cadmium	8 655	10 5	112
Bismuth	9 823	12 3	208
Silver	10 468	13 2	108
Lead	11 376	13 5	207 4
Mercury	13 573	14 5	200
Gold	19 265	12 8	197

In these, as in all the subsequent determinations for the alloys, the weighings were reduced to the vacuum, and the values for S referred to water at 4° C as unity From eight metals twenty eight different kinds of binary alloys can be produced, of these twenty eight combinations eighteen were selected, in each case the two components were fused together in a variety of properly chosen atomic proportions, and the specific gravities of these alloys were determined The net results are summarized in the following table, which, for each combination A, B, in the first two columns gives the composition in multiples of the "atomic weights" given in the table just quoted, while column 3 gives the values of e as calculated by the writer from Matthiesen s numbers for S_0 and S Hence, for example, in the accompanying entries the first line shows that the union into an alloy of twice 118 parts of tin and once 197 parts of gold involves an expansion from 1 volume into 1 004, the second that the union of once 118 parts of tin with four times 197 parts of gold involves a contraction from 1 volume into 1 − 028

Tin and Gold

Antimony and Tin

Sb	Sn	e
12 to 8	1	+ 002
4−2	1	+ 006
1	1 to 2	+ 008
1	3 to 10	+ 005
1	20 to 100	0

Antimony, Bismuth

Sb	Bi	e
2	1 to 12	0

Antimony, Lead

Sb	Pb	e
2	1	+ 008
1	1	+ 006
2	1	0
3	1	+ 0067
5−25	1	0

Tin Cadmium

Sn	Cd	e
6	1	+ 004
4	1	+ 005
2	1 to 8	0
2	12	− 001

Tin, Bismuth

Sn	Bi	e
22	1	0
4	1	− 002
3−1	1	− 005
1	2	− 005
1	4 to 60	0

Tin, Silver

Sn	Ag	e
18	1	− 002
9	1	− 006
6	1	− 008
3	1	− 013
2	1	− 019
1	1	− 024
1	2	− 047
1	4	− 038

Tin, Gold

Sn	Au	e
50	1	0
15−6	1	− 002
4−2 5	1	+ 002
2	1	+ 004
3	2	+ 008
1	1	+ 012
1	2	− 015
1	4	− 028

Tin, Lead

Sn	Pb	e
6	1	+ 003
4	1	+ 002
2	1	0
1	1	+ 0015
1	2−4	+ 005
1	6	+ 004

Cadmium, Bismuth

Cd	Bi	e
3	1−36	0

Cadmium, Lead

Cd	Pb	e
6	1−36	0 to 0025

Bismuth, Silver

Bi	Ag	e
200−2	1	0 to + 002
1	1	− 003
1	2	− 006
1	4	− 007

Bismuth, Gold

Bi	Au	e
90	1	0
40	1	0
20	1	− 003
8	1	− 009
4	1	− 017
2	1	− 035
1	1	− 039
1	2	− 026

Lead, Gold

Pb	Au	e
10	1	− 004
5	1	− 009
4	1	− 006
3	1	− 009
2	1	− 016
1	1	− 018
1	2	− 004
1	4	− 011

Bismuth, Lead		
Bi	Pb	*e*
60—20	1	0
16	1	− 003
12	1	− 005
8	1	− 007
4	1	− 014
2	1	− 024
1	1	− 040
1	2	− 031
1	3	− 020
1	4	− 015
1	5	− 010
1	12	− 004
1	50	0

Lead, Silver			*Gold, Silver*		
Pb	Ag	*e*	Au	Ag	*e*
1	4	− 005	1	6	− 004
1	2	− 003	1	4	− 004
1	1	0	1	2	− 004
2	1	+ 003	1	1	− 002
4	1	+ 006	2	1	− 0025
10	1	+ 004	4	1	− 0027
25		+ 002	6	1	− 0024

Mercury, Tin			*Mercury, Lead*		
Hg	Sn	*e*	Hg	Pb	*e*
1	2	− 009	1	2	+ 002
1	1	− 005	1	1	− 010
2	1	− 007	2	1	− 016

To make these numbers trustworthy it would be necessary to determine their probable errors, and this Matthiesen has not done It would appear that any value of *e* from 0 to (say) ± 002 counts for nothing, and anything up to 004 certainly must be taken as not proving much either way If this is correct, then

(1) No contraction or expansion is proved in the cases Sb, Bi, Cd, Bi, Cd, Pb, Au, Ag,

(2) A contraction (from 0 5 to 4 7 per cent) is proved for Sn, Ag Bi, Ag, Bi, Au, Pb, Au, Pb, Bi, Hg, Sn, Hg, Pb, Sn, Bi (?), Au, Ag (?),

(3) An expansion (from 5 to 0 8 per cent) is proved for Sb, Sn, Sb Pb, Sn, Cd (?), Sn, Pb (?), certain cases of Sn Au and Pb, Ag,

(4) In the two series Sn, Au and Pb, Ag, there are cases both of expansion and of contraction

Thermic and Electric Properties —The specific heat of an alloy, so far as we know, is always in approximate accordance with Dulong and Petit's law Thus the specific heat of Cu_5Al_1 is

$$\frac{(5+1)\times 6\ 4}{5\times 63\ 5+1\times 27},$$

with about the same degree of correctness as the "constant 6 4 can claim for itself

Expansion —Matthiesen, from numerous determinations made with alloys and their components concludes that the expansion of an alloy (from 0° to 100° C) is nearly equal to the sum of the expansions of its components Supposing, for instance, one volume of gold to expand (from 0° to t) by α, and one volume of silver by β then an alloy of four volumes of gold and three volumes of silver expands by $(4\alpha+3\beta)/7$ per unit

Fusibility —In the case of an alloy the melting point and the freezing point are, in general separated by a greater or less interval of temperature, and the latter in itself may have two values as shown by Rudberg, who found that when a fused alloy of tin and lead is allowed to freeze the thermometer becomes stationary at two successive points, as shown in the following table, where x means the number of atomic weights of tin united with y of lead in the given case, and the temperatures are in centigrade degrees

y	∞		
First point	(325)	210	(228°)
Second point	(325)	187	(228)

We see that the first point varies with, while the second, within the range of the experiments, proved independent of, the proportion in which the two metals are united

The melting point of many alloys lies below that of even the more fusible component, as illustrated in the following tables, where the numbers mean parts by weight

Tin and Lead (*Rudberg*)

Per cent of Tin	Per cent of Lead	Melting point
100	0	228°
0	100	325
74	26	194
63	37	186
53	47	196
36	64	241
16	84	249

Name of Alloy	Tin	Lead	Bismuth	Cadmium	Melting point
Newton's	3	2	5	0	100°
Rose's	3	8	8	0	95
Erman's	1	1	2	0	93 7
Wood's	2	4	7	1	70
(Cadmium)	0	0	0	1	(320)

All these alloys melt in boiling water

The electric conductivity of alloys *qua* alloys has been investigated by Matthiesen He confined himself to binary alloys derived from a certain set of elementary metals The main results of his researches are given in ELECTRICITY, vol VIII p 51 For the practical electrician it is important to observe how very much the conductivity of copper is impaired by very minute admixtures even of metals that are good conductors, and also by non metallic contamination, especially with oxygen (present as Cu_2O)

Metallic Substances Produced by the Union of Metals with Small Proportions of Non Metallic Elements

Hydrogen, as was shown by Graham, is capable of uniting with (always very large proportions of) certain metals, notably with palladium, into metal like compounds But those hydrogen alloys, being devoid of metallurgic interest, fall better under the heading PALLADIUM

Oxygen —Mercury and copper (perhaps also other metals) are capable of dissolving their own oxides with formation of alloys Mercury, by doing so, becomes viscid and unfit for its ordinary applications Copper, when pure to start with, suffers considerable deterioration in plasticity But the presence of moderate proportions of cuprous oxide has been found to correct the evil influence of small contaminations by arsenic, antimony, lead, and other foreign metals Most commercial coppers owe their good qualities to this compensating influence

Arsenic combines readily with all metals into true arsenides, which latter, in general, are soluble in the metal itself The presence in a metal of even small proportions of arsenide generally leads to considerable deterioration in mechanical qualities

Phosphorus —The remark just made might be said to hold for phosphorus were it not for the existence of what is called "phosphorus bronze," an alloy of copper with phosphorus (*i e*, its own phosphide), which possesses valuable properties According to Abel, the most favourable effect is produced by from 1 to 1½ per cent of phosphorus Such an alloy can be cast like ordinary bronze, but excels the latter in hardness, elasticity, toughness, and tensile strength See PHOSPHORUS

Carbon —Most metals when in a molten state are capable of dissolving at least small proportions of carbon, which, in general, leads to a deterioration in metallicity, except in the case of iron, which by the addition of small percentages of carbon gains in elasticity and tensile strength with little loss of plasticity (see IRON)

Silicon, so far as we know, behaves to metals pretty much like carbon, but our knowledge of facts is limited What is known as "cast iron" is essentially an alloy of iron proper with 2 to 6 per cent of carbon and more or less of silicon (see IRON) Alloys of copper and silicon were prepared by Deville in 1863 The alloy with 12 per cent of silicon is white, hard, and brittle When diluted down to 4 8 per cent, it assumes the colour and fusibility of bronze, but, unlike it, is tenacious and ductile like iron

Action of the More Ordinary Chemical Agents on Simple Metals

To avoid repetition, let us state beforehand that the metals to be referred to are always understood to be given in the compact (frozen) condition, and that, wherever a series of metals are enumerated as being similarly attacked, the degree of readiness in the action is (so far as our knowledge goes) indicated by the order in which the several members are named,—the more readily changed metal always standing first

Water, at ordinary or slightly elevated temperatures, is decomposed more or less readily, with evolution of hydrogen gas and formation of a basic hydrate, by (1) potassium (formation of KHO), sodium (NaHO), lithium (LiOH), barium, strontium, calcium ($BaO\,H_2$, &c), (2) magnesium, zinc, manganese (MgO_2H_2, &c)

In the case of group 1 the action is more or less violent, and the hydroxides formed are soluble in water and very strongly basylous, metals of group 2 are only slowly attacked, with formation of relatively feebly basylous and practically insoluble hydrates Disregarding the rarer elements (as we propose to do in this section), the metals not named so far may be said to be proof against the action of pure water in the absence of free oxygen (air)

By the conjoint action of water and air, thallium, lead, bismuth are oxidized, with formation of more or less sparingly soluble hydrates ($ThHO$, PbO_2H_2, BiO_3H_3), which, in the presence of carbonic acid, pass into still less soluble basic carbonates

Iron, as everybody knows, when exposed to moisture and air, "rusts," that is, undergoes gradual conversion into a brown ferric hydrate, $Fe_2O_3xH_2O$, but this process never takes place in the absence of air, and it is questionable whether it ever sets in in the absence of carbonic acid What is known is that iron never rusts in solutions of caustic alkalies or lime (which reagents preclude the presence of free carbonic acid), while it does so readily in ordinary moist air containing CO_2 When once started the process proceeds with increasing rapidity, the ferric hydrate produced acting as a carrier of oxygen, it gives up part of its oxygen to the adjoining metal, being itself reduced to (perhaps) Fe_3O_4, which latter again absorbs oxygen from the air to become ferric hydrate and so on (Kuhlmann)

Copper, in the present connexion, is intermediate between iron and the following group of metals

Mercury, if pure, and all the " noble metals (silver, gold, platinum, and platinum metals), are absolutely proof against water even in the presence of oxygen and carbonic acid

The metals grouped together above under 1 and 2 act on steam pretty much as they do on liquid water Of the rest, the following are readily oxidized by steam at a red heat, with formation of hydrogen gas,—zinc, iron, cadmium, cobalt, nickel, tin Bismuth is similarly attacked, but slowly, at a white heat Aluminium is barely affected even at a white heat, if it is pure, the ordinary impure metal is liable to be very readily oxidized

Aqueous Sulphuric or Hydrochloric Acid, of course, readily dissolves groups 1 and 2, with evolution of hydrogen and formation of chlorides or sulphates The same holds for the following group (A) —[manganese, zinc, magnesium] iron, aluminium, cobalt, nickel, cadmium Tin dissolves readily in strong hot hydrochloric acid as $SnCl_2$, aqueous vitriol does not act on it appreciably in the cold, at 150° it attacks it more or less quickly, according to the strength of the acid, with evolution of sulphuretted hydrogen or, when the acid is stronger, of sulphurous acid gas and deposition of sulphur (Calvert and Johnson) A group (B), comprising copper, are, substantially, attacked only in the presence of oxygen or air Lead, in sufficiently dilute acid, or in stronger acid if not too hot, remains unchanged A group (C) may be formed of mercury, silver, gold, and platinum, which are not touched by either aqueous acid in any circumstances

Hot (concentrated) oil of vitriol does not attack gold, platinum, and platinum metals generally, all other metals (including even silver) are converted into sulphates, with evolution of sulphurous acid In the case of iron, ferric sulphate, $Fe_2(SO_4)_3$, is produced, tin yields a somewhat indefinite sulphate of its binoxide SnO_2

Nitric Acid (*Aqueous*)—Gold, platinum, iridium, and rhodium only are proof against the action of this powerful oxidizer Tin and antimony (also arsenic) are converted by it (ultimately) into hydrates of their highest oxides SnO_2, Sb_2O_5 (As_2O_5),—the oxides of tin and antimony being insoluble in water and in the acid itself All other metals, including palladium, are dissolved as nitrates, the oxidizing part of the reagent being generally reduced to nitric oxide, NO, or sometimes to N_2O_3 or N_2O_4 Iron, zinc, cadmium, also tin under certain conditions, reduce the dilute acid, partially at least, to nitrous oxide, N_2O, or nitrate of ammonia, $NH_4\,NO_3 = N_2O + 2H_2O$

Aqua Regia, a mixture of nitric and hydrochloric acids, converts all metals (even gold, the "king of metals," whence the name) into chlorides, except only rhodium, iridium, and ruthenium, which, when pure, are not attacked

Caustic Alkalies—Of metals not decomposing liquid pure water, only a few dissolve in aqueous caustic potash or soda, with evolution of hydrogen The most important of these are aluminium and zinc, which are converted into aluminate, $Al_2O_3 3(K_2$ or $Na_2)O$, and zincate, $ZnO\,RHO$, where $R = K$ or Na respectively But of the rest the majority, when treated with boiling sufficiently strong alkali, are attacked at least superficially, of ordinary metals only gold, platinum, and silver are perfectly proof against the reagents under consideration, and these accordingly are used preferably for the construction of vessels intended for analytical operations involving the use of aqueous caustic alkalies For preparative purposes iron is universally employed and works well, but it is not available analytically, because a superficial oxidation of the empty part of the vessel (by the water and air) cannot be prevented According to the writer's experience basins made of pure malleable nickel are free from this drawback, they work as well as platinum, and rather better than silver ones do There is hardly a single metal which holds out against the alkalies themselves when in the state of fiery fusion, even platinum is most violently attacked In chemical laboratories fusions with caustic alkalies are always effected in vessels made of gold or silver, these metals holding out fairly well even in the presence of air Gold is the better of the two Iron, which stands so well against aqueous alkalies, is most violently attacked by the fused reagents Yet tons of caustic soda are fused daily in chemical works in iron pots without thereby suffering contamination, which seems to show that (clean) iron, like gold and silver, is attacked only by the conjoint action of fused alkali and air, the influence of the latter being of course minimized in large-scale operations

Oxygen or Air—The noble metals (from silver upwards) do not combine directly with oxygen given as oxygen gas (O_2), although, like silver, they may absorb this gas largely when in the fused condition, and may not be proof against ozone, O_3 Mercury, within a certain range of temperatures situated close to its boiling point, combines slowly with oxygen into the red oxide, which, however, breaks up again at higher temperatures All other metals, when heated in oxygen or air, are converted, more or less readily, into stable oxides Potassium, for example, yields peroxide, K_2O_2 or K_2O_4, sodium gives Na_2O_2, the barium group metals, as well as magnesium, cadmium, zinc, lead, copper, are converted into their monoxides MeO Bismuth and antimony give (the latter very readily) sesquioxide (Bi_2O_3 and Sb_2O_3, the latter being capable of passing into Sb_2O_4) Aluminium, when pure and kept out of contact with siliceous matter, is only oxidized at a white heat, and then very slowly, into alumina, Al_2O_3 Tin, at high temperatures, passes slowly into binoxide, SnO_2

Sulphur—Amongst the better known metals, gold and aluminium are the only ones which, when heated with sulphur or in sulphur vapour, remain unchanged All the rest, under these circumstances, are converted into sulphides The metals of the alkalies and alkaline earths, also magnesium, burn in sulphur vapour as they do in oxygen. Of the heavy meals, copper is the one which exhibits by far the greatest avidity for sulphur, its subsulphide Cu_2S being the stablest of all heavy metallic sulphides in opposition to dry reactions See METALLURGY

Chlorine —All metals, when treated with chlorine gas at the proper temperatures, pass into chlorides In some cases the chlorine is taken up in two instalments, a lower chloride being produced first, to pass ultimately into a higher chloride Iron, for instance, is converted first into $FeCl_2$, ultimately into Fe_2Cl_6, which practically means a mixture of the two chlorides, or pure Fe_2Cl_6 as a final product Of the several products, the chlorides of gold and platinum ($AuCl_3$ and $PtCl_4$) are the only ones which when heated beyond their temperature of formation dissociate into metal and chlorine The ultimate chlorination product of copper, $CuCl_2$, when heated to redness, decomposes into the lower chloride, Cu_2Cl_2, and chlorine All the rest, when heated by themselves, volatilize, some at lower, others at higher temperatures

Of the several individual chlorides, the following are liquids or solids, volatile enough to be distilled from out of glass vessels —$AsCl_3$, $SbCl_3$, $SnCl_4$, $BiCl_3$, $HgCl_2$, the chlorides of arsenic, antimony, tin, bismuth, mercury respectively The following are readily volatilized in a current of chlorine, at a red heat —Al_2Cl_6, Cr_2Cl_6, Fe_2Cl_6, the chlorides of aluminium, chromium, iron The following, though volatile at higher temperatures, are not volatilized at dull redness —KCl, NaCl, LiCl, $NiCl_2$, $CoCl_2$, $MnCl_2$, $ZnCl_2$, $MgCl_2$, $PbCl_2$, AgCl, the chlorides of potassium, sodium, lithium, nickel, cobalt, manganese, zinc, magnesium, lead, silver Somewhat less volatile than the last named group are the chlorides (MCl_2) of barium, strontium, and calcium

Metallic chlorides, as a class, are readily soluble in water The following are the most important exceptions —chloride of silver, AgCl, and subchloride of mercury, Hg_2Cl_2, are absolutely insoluble, chloride of lead, $PbCl_2$, and subchloride of copper, Cu_2Cl_2, are very sparingly soluble in water The chlorides $AsCl_3$, $SbCl_3$, $BiCl_3$, are at once decomposed by (liquid) water, with formation of oxide (As_2O_3) or oxychlorides (SbClO, BiClO) and hydrochloric acid The chlorides $MgCl_2$, Al_2Cl_6, Cr_2Cl_6, Fe_2Cl_6 suffer a similar decomposition when evaporated with water in the heat The same holds in a limited sense for $ZnCl_2$, $CoCl_2$, $NiCl_2$, and even $CaCl_2$ All chlorides, except those of silver and mercury (and, of course, those of gold and platinum), are oxidized by steam at high temperatures, with elimination of hydrochloric acid

The above statements concerning the volatilities and solubilities of metallic chlorides form the basis of a number of important analytical methods for the separation of the respective metals

For the characters of metals as chemical elements the reader is referred to the article CHEMISTRY and to the special articles on the different metals (W D)

METAL-WORK Among the many stages in the development of primeval man, none can have been of greater moment in his struggle for existence than the discovery of the metals, and the means of working them The names generally given to the three prehistoric periods of man's life on the earth—the Stone, the Bronze, and the Iron age—imply the vast importance of the progressive steps from the flint knife to the bronze celt, and lastly to the keen-edged elastic iron weapon or tool The length of time during which each of these ages lasted must of course have been different in every country and race in the world The Digger Indians of South California have even now not progressed beyond the Stone Age, while some of the tribes of Central Africa are acquainted with the use of copper and bronze, though they are unable to smelt or work iron

The metals chiefly used have been gold, silver, copper and tin (the last two generally mixed, forming an alloy called bronze), iron, and lead The peculiarities of these various metals have naturally marked out each of them for special uses and methods of treatment The durability and the extraordinary ductility and pliancy of gold, its power of being subdivided, drawn out, or flattened into wire or leaf of almost infinite fineness, have led to its being used for works where great minuteness and delicacy of execution were required, while its beauty and rarity have, for the most part, limited its use to objects of adornment and luxury, as distinct from those of utility In a lesser degree most of the qualities of gold are shared by silver, and consequently the treatment of these two metals has always been very similar, though the greater abundance of the latter metal has allowed it to be used on a larger scale and for a greater variety of purposes

Bronze is an alloy of copper and tin in varying proportions, the proportion of tin being from 8 to 20 per cent The great fluidity of bronze when melted, the slightness of its contraction on solidifying, together with its density and hardness, make it especially suitable for casting, and allow of its taking the impress of the mould with extreme sharpness and delicacy In the form of plate it can be tempered and annealed till its elasticity and toughness are much increased, and it can then be formed into almost any shape under the hammer and punch By other methods of treatment, known to the ancient Egyptians, Greeks, and others, but now forgotten, it could be hardened and formed into knife and razor edges of the utmost keenness In many specimens of ancient bronze small quantities of silver, lead, and zinc have been found, but their presence is probably accidental

In modern times, after the discovery of zinc, an alloy of copper and zinc called brass has been much used, chiefly for the sake of its cheapness as compared with bronze In beauty, durability, and delicacy of surface it is very inferior to bronze, and, though of some commercial importance, has been of but little use in the production of works of art

To some extent copper was used in an almost pure state during mediæval times, especially from the 12th to the 15th century, mainly for objects of ecclesiastical use, such as pyxes, monstrances, reliquaries, and croziers, partly on account of its softness under the tool, and also because it was slightly easier to apply enamel and gilding to pure copper than to bronze (see fig 1) In the mediæval period it was used to some extent in the shape of thin sheeting for roofs, as at St Mark's, Venice, while during the 16th and 17th centuries it was largely employed for ornamental domestic vessels of various sorts

Iron [1]—The abundance in which iron is found in so many places, its great strength, its remarkable ductility and malleability in a red hot state, and the ease with which two heated surfaces of iron can be welded together under the hammer combine to make it specially suitable for works on a large scale where strength with lightness are required—things such as screens, window grills, ornamental hinges, and the like

In its hot plastic state iron can be formed and modelled under the hammer to almost any degree of refinement, while its great strength allows it to be beaten out into leaves and ornaments of almost paper like thinness and delicacy With repeated hammering, drawing out, and annealing, it gains much in strength and toughness, and the addition of a very minute quantity of carbon converts it into steel, less tough, but of the keenest hardness The large employment of cast iron is comparatively modern, in England at least only dating from the 16th century, it is not, however, incapable of artistic treatment if due regard be paid to the necessities of casting, and if no attempt is made to imitate the fine drawn lightness to which wrought iron so readily lends itself At the best, however, it is not generally suited for the finest work, as the great contraction of iron in passing from the fluid to the solid state renders the cast somewhat blunt and spiritless

---

[1] Some recent analyses of the iron of prehistoric weapons have brought to light the interesting fact that many of these earliest specimens of iron manufacture contain a considerable percentage of nickel This special alloy does not occur in any known iron ores, but is invariably found in meteoric iron It thus appears that iron was manufactured from meteorolites which had fallen to the earth in an almost pure metallic state, possibly long before prehistoric man had learnt how to dig for and smelt iron in any of the forms of ore which are found on this planet

Among the Assyrians, Egyptians, and Greeks the use of iron either cast or wrought, was very limited Bronze being the favourite metal for almost all purposes The difficulty of smelting the ore was probably one reason for this, as well as the now forgotten skill which enabled bronze to be tempered to a steel like edge It had however its value of which a proof occurs in Homer (*Il* xxiii), where a mass of iron is mentioned as being one of the prizes at the funeral games of Patroclus

Methods of Manipulation in Metal Work—Gold, silver and bronze may be treated in various ways the chief of which are (1) casting in a mould, and (2) treatment by hammering and punching (French *repoussé*)

The first of these, casting is chiefly adapted for bronze, or in the case of the more precious metals only if they are used on a very small scale The reason of this is that a repoussé relief is of much thinner substance than if the same design were cast, even by the most skilful metal worker, and so a large surface may be produced with a very small expenditure of valuable metal

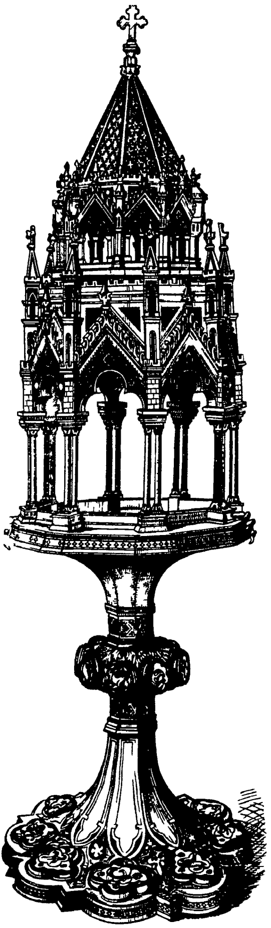


Fig 1—Monstrance of Copper Gilt Italian work of the 15th century

Casting is probably the most primitive method of metal work This has passed through three stages, the first being represented by solid castings such as are most celts and other implements of the prehistoric time the mould was formed of clay, sand, or stone, and the fluid metal was poured in till the hollow was full The next stage was, in the case of bronze, to introduce an iron core, probably to save needless expenditure of the more valuable metal The British Museum possesses an interesting Etruscan or Archaic Italian example of this primitive device It is a bronze statuette from Sessa on the Volturno, about 2 feet high, of a female standing, robed in a close-fitting chiton The presence of the iron core has been made visible by the splitting of the figure, owing to the unequal contraction of the two metals The forearms, which are extended, have been cast separately and soldered or brazed on to the elbows

The third and last stage in the progress of the art of casting was the employment of a core, generally of clay, round which the metal was cast in a mere skin, only thick enough for strength, without waste of metal The Greeks and Romans attained to the greatest possible skill in this process Their exact method is not certainly known, but it appears probable that they were acquainted with the process now called *à cire perdue*—the same as that employed by the great Italian artists in bronze, and still unimproved upon even at the present day Cellini, the great Florentine artist of the 16th century, has described it fully in his *Trattato della Scultura* If a statue was to be cast, the figure was first roughly modelled in clay—only rather smaller in all its dimensions than the future bronze all over this a skin of wax was laid, and worked by the sculptor with modelling tools to the required form and finish A mixture of pounded brick, clay, and ashes was then ground finely in water to the consistence of cream, and successive coats of this mixture were then applied with a brush, till a second skin was formed all over the wax, fitting closely into every line and depression of the modelling Soft clay was then carefully laid on to strengthen the mould, in considerable thickness, till the whole statue appeared like a shapeless mass of clay, round which iron hoops were bound to hold it all together The whole was then thoroughly dried, and placed in a hot oven, which baked the clay, both of the core and the outside mould, and melted the wax, which was allowed to run out from small holes made for the purpose Thus a hollow was left, corresponding to the skin of wax between the core and the mould the relative positions of which were preserved by various small rods of bronze, which had previously been driven through from the outer mould to the rough core The mould was now ready, and melted bronze was poured in till the whole space between the core and the outer mould was full After slowly cooling the outer mould was broken away from outside the statue, and the inner core as much as possible broken up and raked out through a hole in the foot or some other part of the statue The projecting rods of bronze were then cut away, and the whole finished by rubbing down and polishing over any roughnesses or defective places The most skilful sculptors, however, had but little of this after touching to do, the final modelling and even polish which they had put upon the wax being faithfully reproduced in the bronze casting

The further enrichment of the object by enamels and inlay of other metals was practised at a very early period by Assyrian, Egyptian, and Greek metal workers, as well as by the artists of Persia and mediæval Europe

The second chief process, that of hammered work (Greek, *sphyrelata*, French, *repousse*), was probably adopted for bronze work on a large scale, before the art of forming large castings was discovered In the most primitive method thin plates of bronze were hammered over a wooden core, rudely cut into the required shape, the core serving the double purpose of giving shape to and strengthening the thin metal

A further development in the art of hammered work consisted in laying the metal plate on a soft and elastic bed of cement made of pitch and pounded brick The design was then beaten into relief from the back with hammers and punches, the pitch bed yielding to the protuberances which were thus formed, and serving to prevent the punch from breaking the metal into holes The pitch was then melted away from the front of the embossed relief, and applied in a similar way to the back, so that the modelling could be completed on the face of the relief, the final touches being given by the graver This process was chiefly applied by mediæval artists to the precious metals, but by the Assyrians, Greeks, and other early nations it was largely used for bronze

The great gates of Shalmaneser II, 859–824 B C, from Balawat, now in the British Museum, are a remarkable example of this sort of work on a large scale, though the treatment of the reliefs is minute and delicate The "Siris bronzes,' in the same museum, are a most astonishing example of the skill attained by Greek artists in this repoussé work (see Bronsted s *Bronzes of Siris*, 1836) They are a pair of shoulder pieces from a suit of bronze armour, and each has in very high relief a combat between a Greek warrior and an Amazon No work of art in metal has probably ever surpassed these little figures for beauty, vigour, and expression, while the skill with which the artist has beaten these high reliefs out of a flat plate of metal appears almost miraculous The heads of the figures are nearly detached from the ground, their substance is little thicker than paper, and yet in no place has the metal been broken through by the punch They are probably of the school of Praxiteles, and date from the 4th century B C (see fig 2)

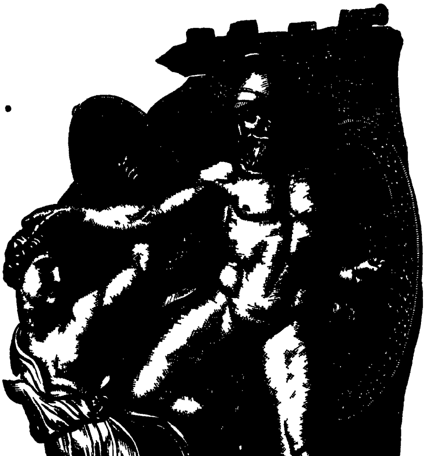


Fig 2 —One of the Siris Bronzes

Copper and tin have been but little used separately Copper in its pure state may be worked by the same methods as bronze, but it is inferior to it in hardness, strength, and beauty of surface Tin is too weak and brittle a metal to be employed alone for any but small objects Some considerable number of tin drinking-cups and bowls of the Celtic period have been found in Cornwall in the neighbourhood of the celebrated tin and copper mines, which appear to have been worked from a very early period The existence of these mines was known to the Phœnicians, who carried on a considerable trade in metals with the south west corner of England and the Scilly Isles —probably the Cassiterides of Pliny and other classical writers

The use of lead has been more extended In sheets it forms the best of all coverings for roofs and even spires In the Roman and mediæval periods it was largely used for coffins, which were often richly ornamented with cast work in relief Though fusible at a very low temperature, and very soft, it has great power of resisting decay from damp or exposure Its most important use in an artistic form has been in the shape of baptismal fonts, chiefly between the 11th and the 14th centuries The superior beauty of colour and durability of old specimens of lead is owing to the natural presence of a small proportion of silver Modern smelters carefully extract this silver from the lead ore, thereby greatly impairing the durability and beauty of the metal

As in almost all the arts, the ancient Egyptians excelled in their metal work, especially in the use of bronze and the precious metals These were worked by casting and hammering, and ornamented by inlay, gilding, and enamels with the greatest possible skill

From Egypt perhaps was derived the early skill of the Hebrews Further instruction in the art of metal working came probably to the Jews from the neighbouring country of Tyre The description of the great gold lions of Solomon s throne, and the laver of cast bronze supported on figures of oxen shows that the artificers of that time had overcome the difficulties of metal working and founding on a large scale The Assyrians were perhaps the most remarkable of all ancient nations for the colossal size and splendour of their works in metal, whole circuit walls of great cities, such as Ecbatana, are said to have been covered with metal plates, gilt or silvered

Herodotus, Athenæus, and other Greek and Roman writers have recorded the enormous number of colossal statues and other works of art for which Babylon and Nineveh were so famed The numerous objects of bronze and other metals brought to light by the excavations of the last forty years in the Tigris and Euphrates valleys, though mostly on a small scale, bear witness to the great skill and artistic power of the people who produced them, while the recent discovery of some bronze statuettes, shown by inscriptions on them to be not later than 2200 B C, proves how early was the development of this branch of art among the people of Assyria

The Metal Work of Greece—The poems of Homer are full of descriptions of elaborate works in bronze, iron, gold and silver, which, even when full allowance is made for poetic fancy, show clearly enough a very advanced amount of skill in the working and ornamenting of these metals among the Greeks of his time His description of the shield of Achilles, made of bronze, enriched with bands of figure reliefs in gold, silver, and tin, could hardly have been written by a man who had not some personal acquaintance with works in metal of a very elaborate kind Again, the accuracy of his descriptions of brazen houses—such as that of Alcinous, *Od* vii 81—is borne witness to by Pausanias's mention of the bronze temple of Athena Χαλκιοικος in Sparta, and the bronze chamber dedicated to Myron in 648 B C, as well as by the discovery of the stains and bronze nails, which show that the whole interior of the so-called treasury of Atreus at Mycenæ was once covered with a lining of bronze plates Of the two chief methods of working bronze, gold, and silver, it is probable that the hammer process was first practised, at least for statues, among the Greeks, who themselves attributed the invention of the art of hollow casting to Theodorus and Rhœcus, both Samian sculptors, about the middle of the 6th century B C Pausanias specially mentions that one of the oldest statues he had ever seen was a large figure of Zeus in Sparta, made of hammered bronze plates riveted together With increased skill in large castings, and the discovery of the use of cores, by which the fluid bronze was poured into a mere skin like cavity, hammered or repoussé work (Greek, *sphyrelata*) was only used for small objects where lightness was desirable, or for the precious metals in order to avoid large expenditure of metal The colossal statues of ivory and gold by Phidias were the most notable examples of this use of gold, especially his statue of Athena in the Parthenon, and the one of Zeus at Olympia The nude parts, such as face and hands, were of ivory while the armour and drapery were of beaten gold The comparatively small weight of gold used by Phidias is very remarkable when the great size of the statues is considered

A graphic representation of the workshop of a Greek sculptor in bronze is given on a fictile vase now in the Berlin Museum (see Gerhard s *Trinkschalen*, plates xii, xiii) One man is raking out the fire in a high furnace, while another behind is blowing the bellows Two others are smoothing the surface of a statue with scraping tools, formed like a strigil A fourth is beating the arm of an unfinished figure, the head of which lies at the workman s feet Perhaps the most important of early Greek works in cast bronze, both from its size and great historical interest, is the bronze pillar (now in the Hippodrome at Constantinople) which was erected to commemorate the victory of the allied Greek states over the Persians at Platæa in 479 B C (see Newton s *Travels in the Levant*) it is in the form of three serpents twisted together, and before the heads were broken off was at least 20 feet high It is cast hollow, all in one piece and has the names of the allied states engraved on the lower part of the coils Its size and the beauty of its surface show great technical skill in the founder s art On it once stood the gold tripod dedicated to Apollo as a tenth of the spoils It is described both by Herodotus and Pausanias

Marble was comparatively but little used by the earlier Greek sculptors, and even Myron, a rather older man than Phidias, seems to have executed nearly all his most important statues in metal

Additional richness was given to Greek bronze work by gold or silver inlay on lips, eyes, and borders of the dress, one remarkable statuette in the British Museum has eyes inlaid with diamonds, and fret work inlay in silver on the border of the chiton

The mirrors of the Greeks are among the most important specimens of their artistic metal work These are bronze disks, one side polished to serve as a reflector, and the back ornamented with engraved outline drawings, often of great beauty (see Gerhard, *Etruskische Spiegel*, 1843-67)

The Greek workman, in fact, was incapable of making an ugly thing Whatever the metal or whatever the object formed, whether armour, personal ornaments, or domestic vessels, the form was always specially adapted to its use, the ornament natural and graceful, so that the commonest water jar was a delight alike to him who made it and those who used it

In metal work, as in other arts, the Romans were pupils and imitators of the Greeks Owing to the growth of that spirit of luxury which in time caused the extinction of the Roman empire, a considerable demand arose for magnificent articles of gold and silver plate The finest specimens of these that still exist are the very beautiful set of silver plate found buried near Hildesheim in 1869, now in the Berlin Museum They consist of drinking vessels, bowls, vases, ladles, and other objects of silver, parcel gilt, and exquisitely decorated with figures in relief, both cast and repoussé There are electrotypes of these in the South Kensington Museum

When the seat of the empire was changed from Rome to Byzantium, the latter city became the chief centre for the production of artistic metal work From Byzantium the special skill in this art was transmitted in the 9th and 10th centuries to the Rhenish provinces of Germany and to Italy, and thence to the whole of Western Europe, in this way the 18th century smith who wrought the Hampton Court iron gates was the heir to the mechanical skill of the ancient metal workers of Phœnicia and Greece

In that period of extreme degradation into which all the higher arts fell after the destruction of the Roman empire, though true feeling for beauty and knowledge of the subtleties of the human form remained for centuries almost dormant, yet at Byzantium at least there still survived great technical skill and power in the production of all sorts of metal work In the age of Justinian (first half of the 6th century) the great church of St Sophia at Constantinople was adorned with an almost incredible amount of wealth and splendour in the form of screens, altars, candlesticks, and other ecclesiastical furniture made of massive gold and silver

Metal Work in Italy —It was therefore to Byzantium that Italy turned for metal workers, and especially for goldsmiths, when, in the 6th to the 8th centuries, the basilica of St Peter s in Rome was enriched with masses of gold and silver for decorations and fittings, the gifts of many donors from Belisarius to Leo III, the mere catalogue of which reads like a tale from the *Arabian Nights* The gorgeous Pala d Oro, still in St Mark s at Venice, a gold retable covered with delicate reliefs and enriched with enamels and jewels, was the work of Byzantine artists during the 11th century This work was in progress for more than a hundred years, and was set in its place in 1106 A D, though still unfinished (see Bellomo, *Pala d'Oro di S Marco*, 1847)

It was, however, especially for the production of bronze doors for churches, ornamented with panels of cast work in high relief, that Italy obtained the services of Byzantine workmen (see Garrucci, *Arte Cristiana*, 1872–82) One artist named Staurachios produced many works of this class, some of which still exist, such as the bronze doors of the cathedral at Amalfi, dated 1066 A D Probably by the same artist, though his name was spelled differently, were the bronze doors of San Paolo fuori le Mura, Rome, careful drawings of which exist, though the originals were destroyed in the fire of 1824 Other important examples exist at Ravello (1197), Salerno (1099), Amalfi (1062), Atrani (1087) and doors at Monreale in Sicily and at Trani, signed by an artist named Barisanos (end of the 12th century), the reliefs on these last are remarkable for expression and dignity, in spite of their early rudeness of modelling and ignorance of the human figure

Most of these works in bronze were enriched with fine lines inlaid in silver, and in some cases with a kind of niello or enamel The technical skill of these Byzantine metal workers was soon acquired by native Italian artists, who produced many important works in bronze similar in style and execution to those of the Byzantine Greeks Such, for example, are the bronze doors of San Zenone at Verona (unlike the others, of repoussé not cast work), those of the Duomo of Pisa, cast in 1180 by Bonannus, and of the

Duomo of Troia, the last made in the beginning of the 12th century by Oderisius of Benevento Another artist named Roger of Amalfi worked in the same way, and in the year 1219 the brothers Hubertus and Petrus of Piacenza cast the bronze door for one of the side chapels in San Giovanni in Laterano One of the most important early specimens of metal work is the gold and silver altar of Sant' Ambrogio in Milan In character of work and design it resembles the Venice Pala d'Oro, but is still earlier in date, being a gift to the church from Archbishop Angilbert II in 835 A D (see Du Sommerard, and D'Agincourt, *Moyen Âge*) It is signed WOLVINIVS MAGISTER PHABER, nothing is known of the artist, but he probably belonged to the semi Byzantine school of the Rhine provinces, according to Dr Rock he was an Anglo-Saxon goldsmith It is a very sumptuous work, the front of the altar being entirely of gold, with repousse reliefs and cloisonnée enamels, the back and ends are of silver, with gold ornaments On the front are figures of Christ and the twelves apostles, the ends and back have reliefs illustrating the life of St Ambrose

The most important existing work of art in metal of the 13th century is the great candelabrum now in Milan cathedral It is of gilt bronze, more than 14 feet high, it has seven branches for candles, and its upright stem is supported on four winged dragons For delicate and spirited execution, together with refined gracefulness of design, it is unsurpassed by any similar work of art Every one of the numerous little figures with which it is adorned is worthy of study for the beauty and expression of the face, and the dignified arrangement of the drapery (see fig 3)

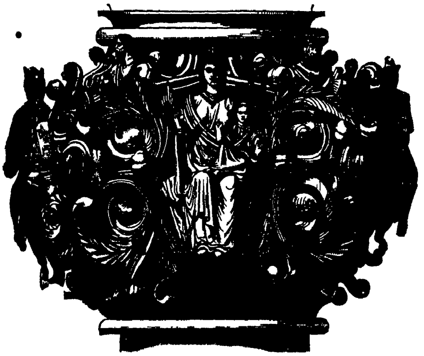


FIG 3 —Boss from the Milanese Candelabrum

The semi-conventional open scroll work of branches and fruit which wind around and frame each figure or group is devised with the most perfect taste and richness of fancy, while each minute part of this great piece of metal work is finished with all the care that could have been bestowed on the smallest article of gold jewellery Though some thing in the grotesque dragons of the base recalls the Byzantine school, yet the beauty of the figures and the keen feeling for graceful curves and folds in the drapery point to a native Italian as being the artist who produced this wonderful work of art There is a cast in the South Kensington Museum

During the 13th and 14th centuries in Italy the widespread influence of Niccolo Pisano and his school encouraged the sculptor to use marble rather than bronze for his work At this period wrought iron came into general use in the form of screens for chapels and tombs, and grills for windows These are mostly of great beauty, and show remarkable skill in the use of the hammer as well as power in adapting the design to the requirements of the material. Among the finest examples of this sort of work are the screens round the tombs of the Scala family at Verona, 1350-75,—a sort of net work of light cusped quatrefoils, each filled up with a small ladder (scala) in allusion to the name of the family The most elaborate specimen of this wrought work is the screen to the Rinuccini chapel in Santa Croce, Florence, of 1371, in which moulded pillars and window like tracery have been wrought and modelled by the hammer with extraordinary skill (see Wyatt, *Metal Work of Middle Ages*) Of about the same date are the almost equally magnificent screens in Sta Trinita, Florence, and at Siena across the chapel in the Palazzo Pubblico The main part of most of these screens is filled in with quatre foils, and at the top is an open frieze formed of plate iron pierced, repoussé, and enriched with engraving

In the 14th century great quantities of objects for ecclesiastical use were produced in Italy, some on a large scale, and mostly the works of the best artists of the time

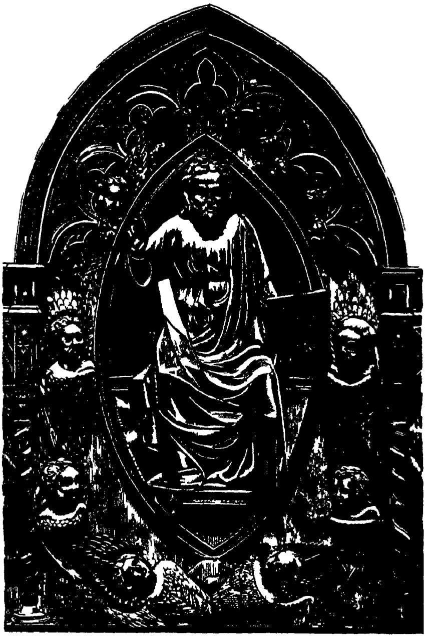


FIG 4 —Silver Repousse Reliefs from the Pistoia Retable

The silver altar of the Florence baptistery is one of the chief of these, it was begun in the first half of the 14th century, and not completed till after 1477 (see *Gaz des Beaux Arts*, Jan 1883) A whole series of the greatest artists in metal laboured on it in succession, among whom were Orcagna, Ghiberti, Verrocchio, Ant Pollajuolo, and many others It has elaborate reliefs in repoussé work, cast canopies, and minute statuettes, with the further enrichment of translucent coloured enamels The silver altar and retable of Pistoia cathedral (see fig 4), and the great shrine at Orvieto, are works of the same class, and of equal importance

Whole volumes might be devoted to the magnificent works in bronze produced by the Florentine artists of this century, works such as the baptistery gates by Ghiberti, and the statues of Verrocchio, Donatello, and many others, but these come rather under the head of sculpture, Some very magnificent bronze screens were produced at this time, especially that in Prato cathedral by Simone, brother of Donatello, in 1444–61, and the screen and bronze ornaments of the tomb of Piero and Giovanni dei Medici in San Lorenzo, Florence, by Verrocchio in 1472.

At the latter part of the 15th century and the beginning of the 16th the Pollajuoli, Ricci, and other artists devoted much labour and artistic skill to the production of candlesticks and smaller objects of bronze, such as door knockers, many of which are works of the greatest beauty. The candlesticks in the Certosa near Pavia, and in the cathedrals of Venice and Padua, are the finest examples of these.

Niccolò Grossi, who worked in wrought iron under the patronage of Lorenzo dei Medici, produced some wonderful specimens of metal work, such as the candlesticks, lanterns, and rings fixed at intervals round the outside of the great palaces (see fig. 5). The Strozzi palace in Florence and the Palazzo del Magnifico at Siena have fine specimens of these—the former of wrought iron, the latter in cast bronze.

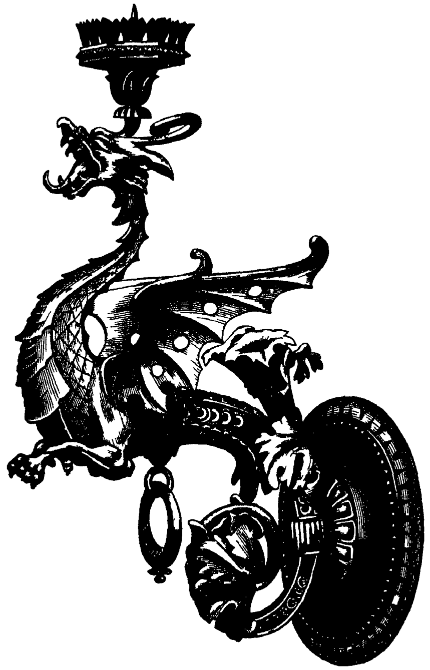


Fig. 5.—Wrought Iron Candle Pricket, late 15th century; Florentine work.

At Venice fine work in metal, such as salvers and vases, was being produced, of almost Oriental design, and in some cases the work of resident Arab artificers. In the 16th century Benvenuto Cellini was supreme for skill in the production of enamelled jewellery, plate and even larger works of sculpture (see Plon's *Ben. Cellini*, 1882) and John of Bologna in the latter part of the same century inherited to some extent the skill and artistic power of the great 15th century artists. Since that time Italy, like other countries, has produced little metal work of real value.

Spain.—From a very early period the metal workers of Spain have been distinguished for their skill, especially in the use of the precious metals. A very remarkable set of specimens of goldsmith's work of the 7th century are the eleven votive crowns, two crosses, and other objects found in 1858 at Guarrazar, and now preserved at Madrid and in Paris in the Cluny Museum (see Du Sommerard, *Musée de Cluny*, 1852). Magnificent works in silver, such as shrines, altar crosses, and church vessels of all kinds, were produced in Spain from the 14th to the 16th century,—especially a number of sumptuous tabernacles (*custodia*) for the host, magnificent examples of which still exist in the cathedrals of Toledo and Seville. The bronze and wrought iron screens—*rejas*, mostly of the 15th and 16th centuries—to be found in almost every important church in Spain are very fine examples of metal work. They generally have moulded rails or ballusters, and rich friezes of pierced and repoussé work, the whole being often thickly plated with silver. The common use of metal for pulpits is a peculiarity of Spain; they are sometimes of bronze, as the pairs in Burgos and Toledo cathedrals, or in wrought iron, like those at Zamora and in the church of San Gil, Burgos. The great candelabrum or *tenebrarium* in Seville cathedral is the finest specimen of 16th-century metal work in Spain; it was mainly the work of Bart. Morel in 1562. It is of cast bronze enriched with delicate scroll work foliage, and with numbers of well modelled statuettes, the general effect being very rich and graceful. Especially in the art of metal work Spain was much influenced in the 15th and 16th centuries by both Italy and Germany, so that numberless Spanish objects produced at that time owe little or nothing to native designers. At an earlier period Arab and Moorish influence is no less apparent.

England.—In Saxon times the English metal workers, especially of the precious metals, possessed great skill, and appear to have produced shrines, altar frontals, retables, and other ecclesiastical furniture of considerable size and magnificence.

Dunstan, archbishop of Canterbury (925–988), like Bernward, bishop of Hildesheim a few years later, and St Eloi of France three centuries earlier, was himself a skilful worker in all kinds of metal. The description of the gold and silver retable given to the high altar of Ely by Abbot Theodwin in the 11th century, shows it to have been a large and elaborate piece of work decorated with many reliefs and figures in the round. In 1241 Henry III. gave the order for the great gold shrine to contain the bones of Edward the Confessor (see W. Burges in *Gleanings from Westminster*). It was the work of members of the Otho family, among whom the goldsmith's and coiner's crafts appear to have been long hereditary. Countless other important works in the precious metals adorned every abbey and cathedral church in the kingdom.

In the 13th century the English workers in wrought iron were especially skilful. The grill over the tomb of Queen Eleanor at Westminster, by Thomas de Leghton, made about 1294, is a remarkable example of skill in welding and modelling with the hammer (see fig. 6).

The rich and graceful iron hinges, made often for small and out-of-the-way country churches, are a large and important class in the list of English wrought iron work. Those on the refectory door of Merton College, Oxford, are a beautiful and well preserved example dating from the 14th century.

More mechanical in execution, though still very rich in effect, is that sort of iron tracery work produced by cutting out patterns in plate, and superimposing one plate over the other, so as to give richness of effect by the shadows produced by these varying planes. The screen by Henry V.'s tomb at Westminster is a good early specimen of this kind of work.

The screen to Bishop West's chapel at Ely, and that round Edward IV.'s tomb at Windsor, both made towards the end of the 15th century, are the most magnificent

English examples of wrought iron, in which every art and feat of skill known to the smith has been brought into play to give variety and richness to the work.

Much wrought-iron work of great beauty was produced at the beginning of the 18th century, especially under the superintendence of Sir Christopher Wren (see Ebbetts, *Iron Work of 17th and 18th Centuries*, 1880). Large flowing leaves of acanthus and other plants were beaten out with wonderful spirit and beauty of curve. The gates from Hampton Court are the finest examples of this class of work (see fig. 7).

From an early period bronze and latten (a variety of brass) were much used in England for the smaller objects both of ecclesiastical and domestic use, but except for tombs and lecterns were but little used on a large scale till the 16th century. The full length recumbent effigies of Henry III. and Queen Eleanor at Westminster, cast in bronze by the "cire perdue" process, and thickly gilt, are equal, if not superior, in artistic beauty to any sculptor's work of the same period (end of the 13th century) that was produced in Italy or elsewhere. These effigies are the work of an Englishman named William Torel (see *Westminster Gleanings*). The gates to Henry VII.'s chapel, and the screen round his tomb at Westminster (see fig. 8), are very elaborate and beautiful examples of "latten" work, showing the greatest technical skill in the founder's art. In latten also were produced the numerous monumental brasses of which about two thousand still exist in England. Though a few were made in the 13th century, yet it was not till the 14th that they came into general use. They are made of cast plates of brass, with the design worked upon them with the chisel and graver. All those, however, to be seen in English churches are not of native work—great quantities of them being Flemish imports (see Cotman, Waller, and Boutell on Monumental Brasses).

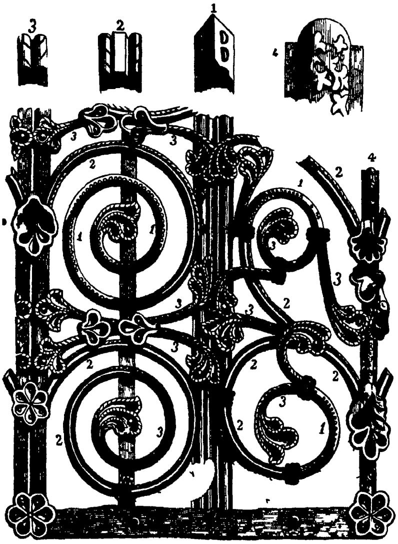


Fig. 6.—Part of the "Eleanor Grill."

• In addition to its chief use as a roof covering, lead was sometimes used in England for making fonts, generally tub-shaped, with figures cast in relief. Many examples exist, *e.g.*, at Tidenham, Gloucestershire; Warborough and Dorchester, Oxon•; Chirton, Wilts; and other places.

Germany.—Unlike England, Germany in the 10th and 11th centuries produced large and elaborate works in cast bronze, especially doors for churches, much resembling the contemporary doors made in Italy under Byzantine influence. Bernward, bishop of Hildesheim, 992–1022, was especially skilled in this work, and was much influenced in design by a visit to Rome in the suite of Otho III. The bronze column with winding reliefs now at Hildesheim was the result of his study of Trajan's column, and the bronze door which he made for his own cathedral shows classical influence, especially in the composition of the drapery of the figures in the panels.

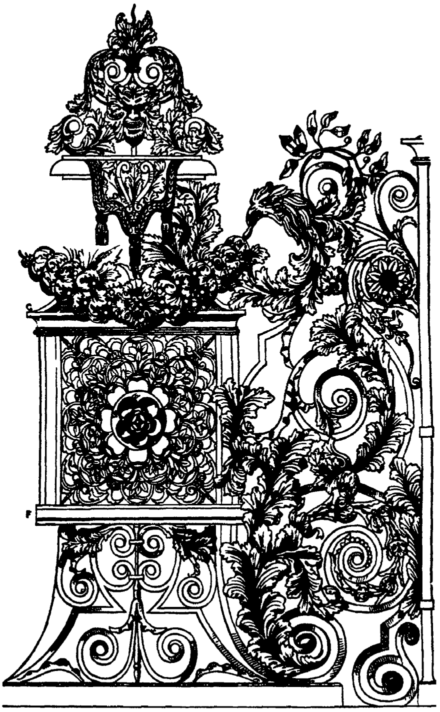


Fig. 7.—Part of one of the Hampton Court Gates.

The bronze doors of Augsburg (1047–72) are similar in style. The bronze tomb of Rudolph of Swabia in Mersburg cathedral (1080) is another fine work of the same school. The production of works in gold and silver was also carried on vigorously in Germany. The shrine of the three kings at Cologne is the finest surviving example.

At a later time Augsburg and Nuremberg were the chief centres for the production of artistic works in the various metals. Herman Vischer, in the 15th century, and his son and grandsons were very remarkable as bronze founders. The font at Wittenberg, decorated with reliefs of the apostles, was the work of the elder Vischer, while Peter and his son produced, among other important works, the shrine of St Sebald at Nuremberg, a work of great finish and of astonishing richness of fancy in its design (see Doebner, *Christliches Kunstblatt*, 1866, Nos. 10–12). The tomb of Maximilian I., and the statues round it, at Innsbruck, begun in 1521, are perhaps the most meritorious German work of this class in the 16th century, and show considerable Italian influence.

In wrought iron the German smiths, especially during the 15th century, greatly excelled Almost peculiar to Germany is the use of wrought iron for grave crosses and sepulchral monuments, of which the Nuremberg and other cemeteries contain fine examples Many elaborate well canopies were made in wrought iron, and gave full play to the fancy and invention of the smith The celebrated 15th century example over the well at Antwerp, attributed to Quintin Massys, is the finest of these

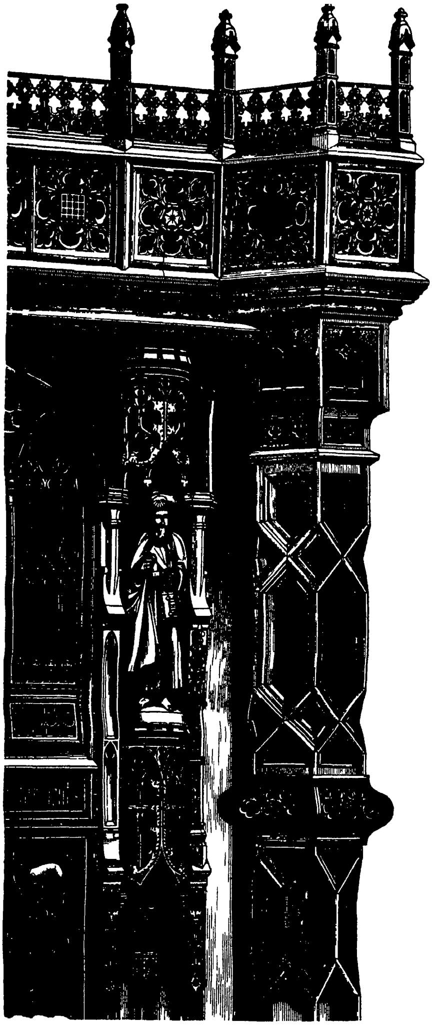


Fig 8 —Part of Henry VII s Bronze Screen

France—From the time of the Romans the city of Limoges has been celebrated for all sorts of metal work, and especially for brass enriched with enamel In the 13th and 14th centuries many life size sepulchral effigies were made of beaten copper or bronze, and ornamented by various coloured "champlevé" enamels The beauty of these effigies led to their being imported into England, most are now destroyed, but a fine specimen still exists at Westminster on the tomb of William de Valence (1296) In ornamental iron work for doors the French smiths were pre eminent for the richness of design and skilful treatment of their metal No examples probably surpass those on the west doors of Notre Dame in Paris—now unhappily much falsified by restoration The crockets and finials on the flèches of Amiens and Rheims are beautiful specimens of a highly ornamental treatment of cast lead, for which France was especially celebrated In most respects, however, the development of the various kinds of metal-working went through much the same stages as in England

Persia and Damascus—The metal workers of the East, especially in brass and steel, were renowned for their skill even in the time of Theophilus, the monkish writer on the subject in the 13th century But it was during the reign of Shah Abbas I (d 1628) that the greatest amount of skill both in design and execution was reached by the Persian workmen Delicate pierced vessels of gilt brass, enriched by tooling and inlay of gold and silver, were among the chief specialties of the Persians (see fig 9)

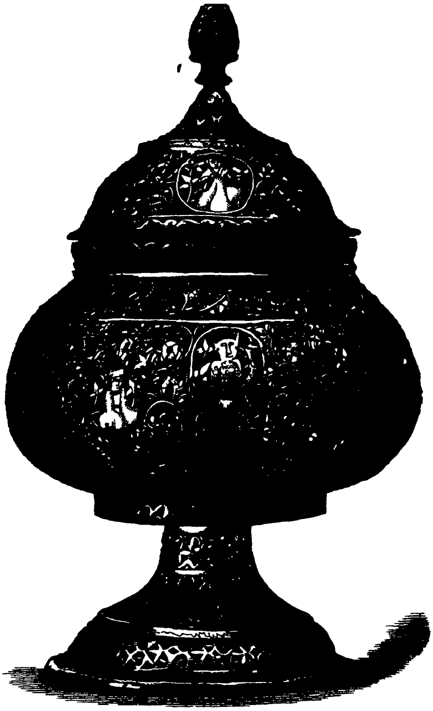


Fig 9 —Brass Vase, pierced and gilt, 17th century Persian work

A process called by Europeans "damascening" (from Damascus, the chief seat of the export) was used to produce very delicate and rich surface ornament A pattern was incised with a graver in iron or steel, and then gold wire was beaten into the sunk lines, the whole surface being then smoothed and polished In the time of Cellini this process was copied in Italy, and largely used, especially for the decoration of weapons and armour The repoussé process both for brass and silver was much used by Oriental workers, and even now fine works of this class are produced in the East, old designs still being adhered to

Recent Metal-Work.—In modern Europe generally the arts of metal-working both as regards design and technical skill are not in a flourishing condition The great bronze lions of the Nelson monument in London are a sad example of the present low state of the founder's art Coarse sand casting in England now takes the place of the delicate "cire perdue" process

Some attempts have lately been made in Germany to revive the art of good wrought-iron work The Prussian gates, bought at a high price for the South Kensington Museum, are large and pretentious, but unfortunately are only of value as a warning to show what wrought iron ought not to be Some English recent specimens of hammered work are more hopeful, and show that one or two smiths are working in the right direction

Literature —PREHISTORIC Worsaae, *Nordiske Oldsager i Kjobenhavn*, 1854, Perrin, *Étude prehistorique—Âge du bronze*, 1870 CLASSICAL Layard, *Nineveh and Babylon*, 1853, Lane s and Wilkinson s works on Ancient Egypt, Pliny, *Natural History*, book xxxiv, Brondsted, *Den Fikoroniske Cista*, 1847, Daremberg, *Dictionnaire des Antiquites*, "Cœlatura, in course of publication Gerhard, various monographs, 1843–67, Muller, *Etrusker*, &c, and other works, Ciampi, *Dell Antica Toreutica*, 1815 MEDIÆVAL Digby Wyatt, *Metal Work of the Middle Ages* 1849, Shaw *Ornamental Metal Work*, 1836 Drury Fortnum, *S K M Handbook of Bronzes* 1877, King, *Orfévrerie et ouvrages en metal du moyen âge* 1852–4, Hefner Alteneck, *Serrurerie du moyen âge* 1869 Viollet le duc, *Dict du mobilier*, "Serrurerie and "Orfevrerie 1858, &c, Lacroix, *Tresor de S Denis*, and *L Art du moyen âge* (various dates) Karch, *Die Rathselbilder an der Broncethure zu Augsburg*, 1869, Krug *Entwurfe fur Gold, Silber, und Bronze Arbeiter* (no date) Linas, *Orfevrerie Merovingienne*, 1864 and *Orfévrerie du XIII^{me} Siècle* 1856 Bordeaux, *Serrurerie du moyen âge*, 1858, Didron, *Manuel des œuvres de bronze et d orfévrerie du moyen âge*, 1859, Du Sommerard, *Arts au moyen âge*, 1838–46 and *Musée de Cluny*, 1852 Durand, *Trésor de l église de Saint Marc a Venise*, 1862 Albert Way, *Gold Retable of Basle*, 1843 Rico y Sinobas, *Trabajos de metales* 1871 Blanchard, *Portes du Baptistère de Florence* 1858, Bock, *Die Goldschmiedekunst des Mittelalters*, 1855, and *Kleinodien des Heil Romischen Reiches*, Jouy, *Les gemmes et les joyaux* 1865, Lubke, *Works of Peter Visscher*, 1877, Adelung, *Die Thuren zu S Sophia in Novgorod*, 1824, Wanderer, *Adam Krafft and his School*, 1868, Nesbitt, "Bronze door of Gnesen Cathedral *Arch Jour*, vol ix, Rossi, *Tre porte di bronzo di Pisa*, Digot, articles in *Bulletin Monumental*, vols xii–xvi, Catalogue of works of art in metal exhibited in 1861 at Ironmongers' Hall, Texier, *Dictionnaire d Orfévrerie*, 1857, Virgil Solis, *Designs for Gold and Silver Smiths*, 1512 (facsimile reproduction, 1862) PRACTICAL TREATISES Theophilus, *Diversarum Artium Schedula*, Cellini, *Trattati dell' Oreficeria e della Scultura*, Vasari, *Tre Arti del Disegno*, part ii, Milanesi s ed, 1882, Garnier, *Manuel du ciseleur*, 1859 (J H M)

METAMORPHOSIS This term has been employed in several distinct senses in biology During the early part of the century it was constantly used to include the current morphological conceptions, as, for instance, of the parts of a flower as modified or "metamorphosed" leaves, or of the segments of a skull as modified vertebræ It is still frequently employed to denote that progressive change from the general to the special undergone by all developing tissues and organs (see BIOLOGY, EMBRYOLOGY), but in this sense is conveniently superseded by the term "differentiation" In the process of animal development, two types are broadly distinguishable,—a fœtal type, in which development takes place wholly or in greater part either within the egg or within the body of the parent, and a larval type, in which the young are born in a condition more or less differing from that of the adult, while the adult stage again is reached in one of two ways, either by a process of gradual change, or by a succession of more or less rapid and striking transformations, to which the term metamorphosis is now usually restricted Metamorphosis is generally regarded as having been brought about by the action of natural selection, partly in curtailing and reducing the phases of development (an obvious advantage in economy of both structural and functional change), and partly also in favouring the acquirement of such secondary characters as are advantageous in the struggle for existence Freshwater and terrestrial animals develop without metamorphosis much more frequently than marine members of the same group, a circumstance which has been variously explained For details of metamorphoses see the articles on the various groups of animals, see also Balfour's *Comparative Embryology*, 1880–81

METAPHYSIC

THE term metaphysic, originally intended to mark the place of a particular treatise in the collection of Aristotle's works, has, mainly owing to a misunderstanding, survived several other titles,—such as "First Philosophy," "Ontology," and "Theology," which Aristotle himself used or suggested Neo Platonic mystics interpreted it as signifying that which is not merely "after" but "beyond" physics, and found in it a fit designation for a science which, as they held, could not be attained except by one who had turned his back upon the natural world And writers of a different tendency in a later time gladly accepted it as a convenient nickname for theories which they regarded as having no basis in experience, in the same spirit in which the great German minister Stein used the analogous title of "metapolitics" for airy and unpractical schemes of social reform A brief indication of the contents of Aristotle's treatise may enable us to give a general definition of the science which was first distinctly constituted by it, and to determine in what sense the subjects which that science has to consider are beyond nature and experience

For Aristotle, metaphysic is the science which has to do with Being as such, Being in general, as distinguished from the special sciences which deal with special forms of being There are certain questions which, in Aristotle's view, we have a right to ask in regard to everything that presents itself as real We may ask what is its ideal nature or definition, and what are the conditions of its realization, we may ask by what or whom it was produced, and for what end, we may ask, in other words, for the formal and the material, for the efficient and the final causes of everything that is These different questions point to different elements in our notion of Being, elements which may be considered in their general relations apart from any particular case of their union These, therefore, the first philosophy must investigate But, further, this science of being cannot be entirely separated from the science of knowing, but must determine at least its most general principles For the science that deals with what is most universal in being is, for that very reason, dealing with the objects which are most nearly akin to the intelligence These, indeed, are not the objects which are first presented to our minds, we begin with the particular, not the universal, with a πρῶτον ἡμῖν which is not πρῶτον φύσει, but science reaches its true form only when the order of thought is made one with the order of nature, and the particular is known through the universal Yet this conversion or revolution of the intellectual point of view is not to be regarded as an absolute change from error to truth, for Aristotle holds that *nihil est in intellectu quod non prius in sensu*, in the meaning that in sense perception there is already the working of that discriminative intelligence[1] which, beginning in sense perception, with the distinction of particular from particular, can rest only when it has apprehended things in their universal forms or definitions Looking at knowledge *formally*, the highest law of thought, the law of contradiction (or, as we might call it, to indicate Aristotle s meaning more exactly, the law of definition or distinction), is already implied in the first act of perception by which one thing is distinguished from another Looking at it *materially*, the reason of man is to be conceived as potentially all that is knowable, *i e*, objects are so related to it that for it to know them in their essential definitions is only to know itself The aim of science, in this view, is to break through the husk of matter, and to apprehend things in their forms, in which they are one with the mind that knows them Hence also it follows that in rising to the most universal science the science of Being in general, the mind is not leaving the region of immediate experience, in which it is at home, for a far off region of abstractions Rather it is returning to itself, apprehending that which is most closely related to itself, and which therefore, though it is late in being made the direct object of investigation, is yet presupposed in all that is, and is known[2]

Metaphysic, then, is the science which deals with the principles which are presupposed in all being and knowing, though they are brought to light only by philosophy Another trait completes the Aristotelian account of it It is theology, or the science of God Now God is *νοησις νοησεως*, pure self consciousness, the absolute thought which is one with its object, and He is therefore the first cause of all existence For, while the world of nature is a world of motion and change in which form is realized in matter, this process of the finite can be explained only by referring it back to an unmoved mover, in whom there is no distinction of matter and form, and who is, therefore, in Aristotle s view, to be conceived as pure form, the purely ideal or theoretic activity of a consciousness whose object is itself Such a conception, however, while it secures the independence and absoluteness of the unmoved mover, by removing him from all relation to what is other than himself, seems to make his connexion with the world inexplicable We can on this theory refer the world to God, but not God to the world Hence Aristotle seems sometimes to say that God is the first mover only as He is the last end after which all creation strives, and this leads him to attribute to nature a desire or will which is directed towards the good as its object or end

Aristotle then brings together in his metaphysic three elements which are often separated from each other, and the connexion of which is far from being at once obvious It is to him the science of the first principles of being It is also the science of the first principles of knowing Lastly, it is the science of God, as the beginning and end of all things, the absolute unity of being and thought, in which all the differences of finite thought and existence are either excluded or overcome

To some this description of the contents of Aristotle s treatise, and especially the last part of it, may seem to be a confirmation of all the worst charges brought against metaphysic For at both extremes this supposed science seems to deal with that which is beyond experience, and which therefore cannot be verified by it It takes us back to a beginning which is prior to the existence as well as to the consciousness of finite objects in time and space, and on to an end to which no scientific prophecy based upon our consciousness of such objects can reach In the former aspect of it, it has to do with notions so abstract and general that it seems as if they could not be fixed or tested by reference to any experience, but must necessarily be the playthings of dialectical sophistry In the latter aspect of it, it entangles us in questions as to the final cause and ultimate meaning of things, questions involving so comprehensive a view of the infinite universe in which we are insignificant parts that it seems as if any attempt to answer them must be for us vain and presumptuous On both sides, therefore, metaphysic appears to be an attempt to occupy regions which are beyond the habitable space of the intelligible world—to deal with ideas which are either so vague and abstract that they cannot be fastened to any definite meaning, or so complex and far reaching that they can never by any possibility be verified For beings like men, fixed within these narrow limits of space and time, the true course, it would seem, is to "cultivate their gardens, asking neither whence they come nor whither they go, or asking it only within the possible limits of history and scientific prophecy To go back to the beginning or on to the end is beyond them, even in a temporal, still more in a metaphysical, sense That which is *πρῶτον φυσει* escapes us even more absolutely than the prehistorical and pregeological records of man and his world That which is *ὕστατον φυσει* escapes us even more absolutely than the far off future type of civilization, which social science vainly endeavours to anticipate Our state is best pictured by that early Anglican philosopher who compared it to a bird flying through a lighted room "between the night and the night The true aim of philosophy is, therefore, it would seem, to direct our thoughts to the careful examination and utilization of the narrow space allotted to us by an inscrutable power, and with scientific self restraint to refrain from all speculation either on first or on final causes

The main questions as to the possibility and the nature of metaphysic, according to Aristotle s conception of it, may be summed up under two heads We may ask whether we can in any sense reach that which is beyond experience, and, if so, whether this "beyond' is a first or a last principle, a pre condition or a final cause of nature and experience, or both The former question branches out into two, according as we look at metaphysic from the objective or the subjective side, or, to express the matter more accurately, according as we consider it in relation to those natural objects which are *merely* objects of knowledge, or in relation to those spiritual objects which are also subjects of knowledge We shall therefore consider metaphysic, first, in relation to science in general, and, secondly, in relation to the special science of psychology The latter question also has two aspects, for, while the idea of a first cause or principle points to the connexion between metaphysic and logic, the idea of a last principle or final cause connects metaphysic with theology We shall therefore consider in the third place the relation of metaphysic to logic, and in the fourth place its relation to religion and the philosophy of religion

1 *The Relation of Metaphysic to Science* —The beginnings of science and metaphysic are identical, though there is a sense in which it may be admitted that the metaphysical comes before the scientific or positive era The first efforts of philosophy grasp at once at the prize of absolute knowledge No sooner did the Greeks become dissatisfied with the pictorial synthesis of mythology by which their thoughts were first lifted above the confusion of particular things, than they asked for one universal principle which should explain all things The Ionic school sought to find some one phenomenon of nature which might be used as the key to all other phenomena The Eleatics, seeing the

---

[1] *Δυναμις κριτική*, *Anal Post*, ii 99*b*

[2] What is said here as to the intelligence is partly taken from the *De Anima* The necessary qualifications of the above general statement of Aristotle s views will be given subsequently

futility of making one finite thing the explanation of all other finite things, tried to find that explanation in the very notion of unity or being itself. We need not underestimate the speculative value of such bold attempts to sum up all the variety of the world in one idea, but it is obvious that they rather give a name to the problem than solve it, or that they put the very consciousness of the problem in place of the solution of it. Science is possible only if we can rise from the particular to the universal, from a subjective view of things as they immediately present themselves to us in perception to an objective determination of them through laws and principles which have no special relation to any particular set of events or to any one individual subject. But this is only one aspect of the matter. To advance from a conception of the world *in ordine ad individuum* to one *in ordine ad universum*, and so to discount and eliminate what is merely subjective and accidental in our first consciousness of the world, is the beginning of knowledge. But little is gained unless the universal, which we reach through the negation of the particulars, is more than their mere negation, unless it is a law or principle by means of which we can explain the particulars. Now the defect of early philosophy was that its universal was "the one beyond the many," not the "one in the many,"—in other words, that it was not a law or principle by which the particulars subsumed under it could be explained, but simply the abstraction of an element common to them. But the process of knowledge is a process that involves both analysis and synthesis, negation and reaffirmation of the particulars with which we start. If we exaggerate the former aspect of it, we enter upon the *via negativa* of the mystics, the way of pure abstraction and negation, which would open the mind to the ideal reality of things simply by shutting it to all the perceptions of sensible phenomena. And, if we follow out this method to its legitimate result, we must treat the highest abstraction, the abstraction of Being, as if it were the sum of all reality, and the Neo Platonic ecstasy in which all distinction, even the distinction of subject and object, is lost as the only attitude of mind in which truth can be apprehended.

In the philosophy of the Socratic school we find the first attempt at a *systematic* as opposed to an *abstract* theory—the first attempt to bring together the one and the many, and so to determine the former that it should throw light upon the latter. Yet even in Plato the tendency to oppose the universal to the particular is stronger than the tendency to relate them to each other, and in some of his dialogues, as, *e.g.*, in the *Phædo*, we find a near approach to that identification of the process of knowledge with abstraction which is the characteristic of mysticism. Aristotle, therefore, had some ground for taking the Platonic principle that "the real is the universal" in a sense which excludes the reality of the individual. Yet, though he detected Plato's error in opposing the universal to the particular, and though, at the same time, he did not entirely lose sight of the truth which Plato had exaggerated, that the particular is intelligible only *through* the universal, Aristotle was not able to escape the influence of that dualism which had marred the philosophy of his predecessor. Hence the effect of his protest against a philosophy of abstraction was partly neutralized by his separation between the divine Being as pure form and nature as the unity of form and matter, and again by his separation of the pure reason which apprehends the forms of things from the perceptions of sense which deal with forms realized in matter. And after Aristotle's time the tendency of philosophy was more and more to withdraw from contact with experience. The Neo-Platonic philosophy, and the Christian theology which was so strongly influenced by it, contained, indeed, an idea of the reconciliation of God and nature, and hence of form and matter, which must ultimately be fatal to dualism, and therefore to the method of mere abstraction. But the explicit meaning of the philosophy of the Middle Ages was still dualistic, and the mode in which the Aristotelian formulæ were wrought into the substance of Christian doctrine by the scholastics tended more and more to conceal that idea of the unity of opposites which was involved in Christianity. Hence mediæval realism presented, in its most one-sided form, the doctrine that "the real is the universal," meaning by the universal nothing more than the abstract. And, as a natural consequence, the modern insurrection of the scientific spirit against scholasticism took its start from an equally bald and one sided assertion of the opposite principle, that "the real is the individual," meaning by that the individual of immediate perception. If Platonism had dwelt too exclusively on one aspect of the process of knowledge, viz., that it seeks to rise above the particular, the sensible, the subjective, to the universal, the intelligible, the objective, as if in the latter alone were reality to be found, modern men of science learnt from their first nominalistic teachers to regard the universal as nothing more than an abbreviated expression for the particulars, and science itself as a mere generalization of the facts of sensible perception. But this view of scientific knowledge, as a mere reaffirmation of what is immediately given in sense, is as imperfect as the opposite theory, which reduces it to the mere negation of what is so given. An ideal world utterly and entirely divorced from the phenomenal, and an ideal world which is simply a repetition of the phenomenal, are equally meaningless. The processes of science have both a negative and a positive side; they involve a negation of the particular as it is immediately presented in sense, but only with a view to its being reaffirmed with a new determination through the universal. The fact as it is first presented to us is not the fact as it is; for, though it is from the fact as given that we rise to the knowledge of the law, it is the law that first enables us to understand what the fact really means. Our first consciousness of things is thus, not an immovable foundation upon which science may build, but rather a hypothetical and self-contradictory starting point of investigation which becomes changed and transformed as we advance.

The nominalism of scientific men in modern times is due to two special causes, one of which has already been mentioned. It is partly due to the traditions of a time when mediæval realism was the great enemy of science. The Baconian protest against the "anticipation of nature" was a relative truth when it was urged against a class of writers who supposed that true theories could be attained without regard to facts; the Baconian assertion of the necessity of attending to *axiomata media* was the necessary correction of the tendencies of mystics, who supposed that philosophy could attain its end by grasping at once at absolute unity, and contented themselves, therefore, with a unity which did nothing to explain the differences. But, when the former was turned into the dogmatic assertion that the mind is, or ought to be, passive in the process of knowledge, as having in itself no principle for the explanation of things, and when the latter was turned into the dogmatic assertion that science can only proceed from part to part and never from the whole to the parts, these relative truths became a source of error. And this error was confirmed and increased by the mistaken views of those who first tried to correct it. For these, admitting that scientific truth is entirely derived from external experience, only ventured to assert the existence of *a priori* knowledge alongside of, and in addition to, that which is *a posteriori*. In other words, they sought in inner experience a basis for those beliefs which outward experience seemed unable to support But this basis was soon found to be treacherous Introspection, observation of the inner life as opposed to and distinguished from the outer life, could be only an observation of the facts of the individual consciousness as such, and to base religion and morality on such a foundation was to treat God and right as subjective phenomena, which do not necessarily correspond to any objective reality Nor was this conclusion really evaded by the assertion of the self evidencing necessity of such ideas and beliefs, or of the principles upon which they are founded For this necessity, as a subjective phenomenon, might be accounted for otherwise than by the supposition of their objective validity Such scepticism, further, was favoured by the progress of science, which, as it advanced from physics to biology and sociology, became more and more inconsistent with the idea of an absolute breach between inner and outer experience, and narrowed the sphere which had been hitherto reserved for the former Man, it was urged, is but a part in a greater whole, not exempted from the law of action and reaction which connects all parts of that whole with each other His individual life contains only a few links in a chain of causation that goes back to a beginning and onward to an end of which he knows nothing And, as Spinoza says, *vis qua unaquæque res in existendo perseverat a causis externis infinite superatur* Hence to treat ideas which are only states of the individual consciousness as the explanation of the world, instead of treating them as phenomena to be explained by its relation to that world, seemed to be an absurdity The particular beliefs and tendencies of the mind were to be regarded, not as ultimate facts in reference to which everything is to be interpreted, but rather as facts which are themselves to be referred to more general causes and laws It thus appeared that the attempt to divide truth into an *a posteriori* and an *a priori* part, the latter of which should find its evidence in an inner experience as the former in an outer experience, is an illusive process If the *a priori* is reduced to the level of the *a posteriori*, it becomes impossible to base on the *a priori* any beliefs that go beyond the range of subjective experience If the self and the not self are taken simply as different finite things, which we can observe in turn, their relations must be brought under the general laws of the connexion of finite things with each other, and the phenomena of mind must be treated, like the phenomena of matter, as facts to be accounted for according to these laws

But this of itself indicates a way of escape both from the introspective theory and from the empiricism to which it is opposed For it suggests the question—What is the source of those very laws which guide the procedure of science in accounting for facts, psychological facts among others? When a scientific psychologist of the modern school attempts to show how by habituation of the individual and the race the necessity of thought expressed in the law of causation was produced in the minds of the present generation of men, it is obvious that his whole investigation and argument presuppose the law whose genesis he is accounting for A glaring instance of such circular reasoning is found in the writings of the most prominent representative of the school in the present day Mr Spencer begins by laying down as a first postulate of science that necessity of thought must be taken as a criterion of truth It is by the continual aid of this postulate that he constructs his system of nature, and finally his psychological theory of the development of consciousness in man Yet the main object of this psychological theory seems to be to account for the very necessities with which the author starts Obviously such a philosophy contains elements of which the author is imperfectly conscious, for it involves that mind is not only the last product but the first presupposition of nature, or, in other words, that in mind nature returns upon its first principle But to admit this is at once to lift the conscious being as such above the position which he would hold as merely a finite part of a finite world It is to assert that nature has an essential relation to a consciousness which is developed in man, and that in the growth of this consciousness we have, not an evolution which is the result of the action of nature as a system of external causes *upon him*, but an evolution in which nature is really "coming to itself,' i e, coming to self consciousness, *in him*

Now it was Kant who first—though with a certain limitation of aim—brought this idea of the relativity of thought and being to the consciousness of the modern world In the *Critique of Pure Reason*, thought, indeed, is not set up as an absolute *prius*, in relation to which all existence must be conceived, but it is set up as the *prius* of experience, and so of all existences which are objects of our knowledge Experience is for Kant essentially relative to the conscious self, it exists through the necessary subsumption of the forms and matter of sense under the categories, as, on the other hand, the consciousness of self is recognized as essentially dependent on this process On this view, the *a priori* and *a posteriori* factors of experience do not really exist apart as two separate portions of knowledge If they are severed, each loses all its meaning Perceptions in themselves are void, categories in themselves are empty We do not look outwards for one kind of truth and inwards for another, nor do we even, by an external process, bring facts given as contingent under principles recognized as necessary, but the *a priori* is the condition under which alone the *a posteriori* exists for us Even if it is allowed that the facts of inner and outer experience contain a contingent element or matter, given under the conditions of time and space, yet neither time nor space nor the facts of experience conditioned by them exist for us except as elements of an experience which is organized according to the categories

This is the essential truth which Kant had to express It is marred in his statement of it by the persistent influence of the abstract division between contingent matter given from without and necessary principles supplied from within, a division essentially inconsistent with the attempt to show that the contingent matter is necessarily subsumed under these principles, and indeed exists for us only as it is so subsumed But Kant himself puts into our hands the means of correcting his own inadequacy, when he reduces the inaccessible thing in itself, which he at first speaks of as affecting our sensibility and so giving rise to the contingent matter of experience, to a noumenon (*νοουμενον*) which is projected by reason itself The *Dialectic* exhibits the idea of thought as not only constituting finite experience but also reaching beyond it, though as yet only in a negative way The mind is, on this view, so far unlimited that it knows its own limits, it is conscious of the defects of its experience, of the contingency of its sensible matter, and the emptiness and finitude of its categories, and by reason of this consciousness it is always seeking in experience an ideal which it is impossible to realize there Thought measures experience by its own nature, and finds it wanting It demands a kind of unity or identity in its objects which it is unable to find in the actual objects of experience It is this demand of reason which lifts man above a mere animal existence, and forces him by aid of the categories to determine the matter of sense as a world of objects, yet, as this finite world of experience can never satisfy the demand of reason, the consciousness of it is immediately combined with the consciousness of its limited and phenomenal character. The student of the *Critique of Pure Reason* cannot but recognize the strange balance between the real and the phenomenal in which it ends, allowing to man the consciousness of each so far as to enable him to see the defects of the other,—so that by aid of the pure identity of reason he can criticize and condemn the "blindness" or unresolved difference of experience, and by means of the concreteness and complexity of experience he can condemn the "empty" identity of reason.

In order, however, to understand the full bearing of Kant's criticism of knowledge, and at the same time to find the meeting point of the opposite currents of thought which alternately prevail in it, it will be necessary to consider the subject a little more closely. The lesson of the *Critique* may be gathered up into two points. In the first place, it is a refutation of the ordinary view of experience as something immediately given for thought and not constituted by it. In the second place, it is a demonstration of the merely phenomenal character of the objects of experience, *i.e.*, the demonstration that the objects of experience, even as determined by science, are not things in themselves. Both these results require to be kept clearly in view if we would understand the movement of thought excited by Kant. On the one hand Kant had to teach that what is ordinarily regarded as real, the world of experience, is transcendently ideal, *i.e.*, is determined as real by *a priori* forms of thought. On the other hand he had to teach that the world so determined is empirically and not transcendentally real, *i.e.*, its reality is merely phenomenal. With the former lesson he met the man of science, and compelled him to renounce his materialistic explanation of the world as a thing which exists in independence of the mind that knows it. The world we know is a world which exists only as it exists *for us*, for the thinking subject; hence the thinking subject, the ego, cannot be taken as an object like other objects, an object the phenomena of which are to be explained like other phenomena by their place in the connexion of experience. Having, however, thus repelled scientific materialism by the proof that the reality of experience is ideal, Kant refuses to proceed to the complete identification of reality with ideality, and meets the claims of the metaphysician with the assertion that the reality of experience is merely phenomenal. Hence he rejects any idealism that would involve the negation of things in themselves beyond phenomena, or the identification of the objects of experience with these things. The reality we know is a reality which exists only for us as conscious subjects, but this, though it is the only reality we can know, is not the absolute reality.

It is, however, to be observed that the nature of this opposition between phenomena and things in themselves seems to change as we advance from the *Analytic*, where the existence of such things is presupposed, to the *Dialectic*, where the grounds of that presupposition are examined. At first the opposition seems to be between what is present in consciousness and what is absolutely beyond consciousness. The matter of experience is regarded as given externally in the affections of the sensible subject,—affections caused by an unknown thing in itself, of which, however, they can tell us nothing. On the other hand the form of experience, the categories and principles of judgment which turn these affections into objects of knowledge, are not pure expressions of the real nature, the pure identity, of the subject in itself, but only products of the identity of the self in relation to the sensibility and its forms of time and space. Hence, on both sides we must regard experience as merely phenomenal, i.e., in relation to the noumenal object and in relation to the noumenal subject, which lurk behind the veil and send forth into experience on the one side affections which become objects through their determination by the unity of thought, and on the other side an identity of thought which becomes self-conscious in relation to the objects so determined by itself.

Kant, however, having thus answered the question of the possibility of experience by reference to two things in themselves which are out of experience, is obliged to ask himself how the *consciousness* of these two things in themselves, and the criticism of experience in relation to them, is possible. And here, obviously, the opposition can no longer be conceived as an opposition between that which is and that which is not in consciousness. For the things in themselves must be present to consciousness in some fashion in order that they may be contrasted with the phenomena. If, therefore, phenomena are now regarded as unreal, it must be because we have an *idea of reality* to which the reality of experience does not fully correspond. In the *Analytic* Kant had been speaking as if the real consisted in something which is not present to the conscious subject at all, though we, by analysis of his experience, can refer to it as the cause of that which is so present. Now in the *Dialectic* he has to account for the fact that the conscious subject himself is able to transcend his experience, and to contrast the objects of it as phenomenal with things in themselves.

Now it is obvious that such an opposition is possible only so far as the thought, which constitutes experience, is at the same time conscious of itself in opposition to the experience it constitutes. The reason why experience is condemned as phenomenal is, therefore, not because it is that which exists for thought as opposed to that which does not exist for thought, but because it imperfectly corresponds to the determination of thought in itself. In other words, it is condemned as unreal, not because it is ideal, but because it is *imperfectly* ideal. And the absolute reality is represented, not as that which exists without relation to thought, but as that which is identical with the thought for which it is. In the *Dialectic*, therefore, the noumenon is substituted for the thing in itself, and the noumenon is, as Kant tells us, the object as it exists for an intuitive or perceptive understanding, *i.e.*, an understanding which does not synthetically combine the given matter of sense into objects by means of categories, but whose thought is one with the existence of the objects it knows. It is the idea of such a pure identity of knowing and being, as suggested by thought itself, which leads us to regard our actual empirical knowledge as imperfect, and its objects as not, in an absolute sense, *real* objects. The noumena are not, therefore, the unknown causes by whose action and reaction conscious experience is produced; they represent a unity of thought with itself to which it finds experience inadequate. This higher unity of thought with itself is what Kant calls reason, and he identifies it with the faculty of syllogizing. Further, he finds in the three forms of syllogism a guiding thread which brings him to the recognition of three forms in which the pure unity of reason presents itself to us in opposition to the merely *synthetic* unity of experience, a psychological, a cosmological, and a theological form. In each of these cases the empirical process of knowledge is accompanied, guided, and stimulated by an idea which nevertheless it is unable to realize or verify. In psychology we have ever present to us an idea of the identity of the self, which is never realized in our actual self-consciousness, because the self of which we are conscious is manifold in its states and because it stands in relation to an external world. The idea of simple identity is, therefore, something we may set before us as the goal of an ideal psychology, to which we may approximate in so far as we can trace unity of faculty through all the differences of mental phenomena, but to which we can never attain owing to the nature of the matter with which we deal. Again, in our scientific attempts to explain our external experience, the unity of reason takes the form of an idea of the world as a completed infinite whole, which contains all the objects known to us and all other possible objects, but this cannot be realized in an experience which is conditioned by space and time, and is, therefore, ever incomplete. The idea of totality is therefore, an *ideal*, which guides and stimulates our scientific progress, without which such a thing as science could not exist, but which at the same time can never be realized by science. Lastly, the unity of reason takes a third form in which identity and totality are combined,—as the idea of a unity in which all differences, even the difference of subject and object, are transcended,—the idea of a unity of all things with each other and with the mind that knows them. This idea also is one which science can neither surrender nor realize. It cannot surrender it without giving up that striving after unity without which science would not exist, and it cannot realize it, for the difference between the world as it is presented to us in actual experience and the subjective determination of our thinking consciousness cannot be overcome. We can, indeed, use the idea that the world is an organic whole, determined in relation to an end which consciousness sets for itself, as an *heuristic* principle to guide us in following the connexion of things with each other, but, as we cannot by means of any such idea anticipate what the facts of external experience will be, so we cannot prove that for a mind other than ours the unity of things which we represent in this way might not take a quite different aspect. Indeed we have reason to think it would, for, while we always think of a designing mind as using materials which have an existence and nature independent of the purposes to which they are put, the absolute mind must be conceived as creating the materials themselves by the same act whereby they are determined to an end. We must conceive it, in short, as an intuitive understanding for which end and means, objective and subjective, are one, or, in other words, as an intelligence whose consciousness of itself is or contains the existence of all that is object for it.

This new view of the things in themselves as *noumena* or ideals of reason involves a new attitude of thought towards them different from that dogmatic attitude which is provisionally adopted in the *Analytic*. Accordingly, we now find Kant speaking of them, not as things which exist independently of their being conceived, but as "problematical conceptions' of which we cannot even determine whether they correspond to any objects at all. They are "limitative' notions which have a negative value, in so far as they keep open a vacant space beyond experience, but do not enable us to fill that space with any positive realities. They are like dark lanterns which cast light upon the empirical world, and show what are its boundaries, but leave their own nature in obscurity. All that we can say of the noumenal self or subject is that it corresponds to the unity implied in all knowledge, but whether there is such a self, independent of the process of empirical synthesis and the self consciousness which accompanies that process, we cannot tell. All that we can say of the noumenal reality of the objective world is that it corresponds to the idea of the objects of experience as a completed whole in themselves apart from the process whereby we know them, but whether there is any such real world independent of the process of experience it is impossible to say. Lastly, all that we can say of God is that He corresponds to the idea of the unity of all things with the mind that knows them,—an ideal which is involved in all knowledge,—but whether the realization of this idea in an intuitive understanding is even possible we have no means of determining, however we may suspect that understanding and sensibility are "branches springing from the same unknown root." The *Criticism of Pure Reason* ends, therefore, in a kind of seesaw between two forms of consciousness—a thinking consciousness, which transcends experience and sets before us an idea of absolute reality, but which cannot attain to any knowledge or even certitude of any object corresponding to this idea, and an empirical consciousness, which gives us true knowledge of its objects, but whose objects are determined as merely phenomenal and not absolutely real.

The equipoise thus maintained between the empirical and the intelligible world is, however, in the *Critique of Practical Reason*, overbalanced in favour of the latter. What the theoretical reason could not do "in that it was weak through the flesh," through its dependence on the very empirical consciousness which it sought to transcend, is possible to the practical reason, because it is primarily determined by itself. In our moral consciousness we find ourselves under a law which calls upon us to *act* as beings who are absolutely self determined or free, and which, therefore, assures us that our intelligible self is our real self, and conclusively determines our empirical self in contrast with it as phenomenal. Thus the moral law gives reality to the intelligible world, or, as Kant expresses it, "the idea of an intelligible world is a point of view beyond the phenomenal which the reason sees itself compelled to take up, in order to think of itself as practical. In other words, the moral law presupposes freedom or determination in the rational being as such, and makes him regard himself, not merely as a link in the chain of conditioned existences in time and space, but as the original source of his own life. The blank space beyond the phenomenal thus begins to be filled up by the idea of a free causality which again postulates a world adequate and conformable to itself. And the man who, as an empiric individuality, is obliged to regard himself merely as an individual being determined by other individual beings and things is authorized as a moral being to treat this apparent necessity as having its reality in freedom, and to look upon himself as the denizen of a spiritual world where nothing is determined for him from without which is not simply the expression of his own self determination from within. "Thus we have found, what Aristotle could not find, a fixed point on which reason can set its lever, not in any present or future world, but in its own inner idea of freedom,—a point fixed for it by the immovable moral law, as a secure basis from which it can move the human will, even against the opposition of all the powers of nature.[1] Starting from this idea of freedom, therefore, Kant proceeds to reconstruct for *faith* the unseen world, which in the *Critique of Pure Reason* he had denied as an object of *knowledge*. Nor is he content to leave the two worlds in sharp antithesis to each other, but even in the *Critique of Practical Reason*, and still more in the *Critique of Judgment*, he brings them into relation to each other, and so gives to theoretical reason a kind of authority to use for the explanation of the phenomenal world those ideas which of itself it might be inclined to regard as illusive.

In all this, however, it is difficult to avoid seeing a partial retractation of Kant's first views as to the irreconcilable opposition of the phenomenal and the noumenal. For, in the first place, the moral imperative is addressed to a self which is at one and the same time regarded in both characters, and which is called upon to subsume under the moral law acts which otherwise derive their character and meaning from the relations of the phenomenal world. That the particular nature of men as phenomenal individuals can be the means of realizing the universal law of reason is implied in all Kant's statements of the latter, and particularly in his conception of men as constituting together a "kingdom of ends", for it is difficult to conceive this kingdom otherwise than as an organic unity of society, in which each individual, by reason of his special tendencies and capacities, has a definite office to fulfil in realizing the universal principle that binds all the members of the kingdom to each other. The *summum bonum*, again, is said to consist in the union of happiness with goodness, *i.e.*, of the empirical conditions of man's individual life as a sensible subject with the pure self-determination of the intelligible self; and God is postulated as a *Deus ex machina* to bind together these two unrelated elements,—a conception which shows the difficulty into which Kant has brought himself by defining them as unrelated. Still more obvious is the effort of Kant to get beyond the dualism of his first view of things in the *Critique of Judgment*. For in that work he maintains that the consciousness of the beautiful and the sublime is or involves a harmony of the understanding or the reason with sense; and, what is still more important, he points out that the idea of organic unity, without which we cannot explain the phenomena of life, contains in it a possibility of the reconciliation of freedom and necessity, of the intelligible and the phenomenal. This idea, he argues, we are authorized by our moral consciousness to apply to the whole course of the things in the phenomenal world, and so to regard it as a process to realize the moral ideal. No doubt he again partially retracts this view when he declares that we must treat the idea of final causality as merely a *subjective* principle of judgment, which, even in the case of living beings, is to be regarded only as necessary for us as finite intelligences. But such saving clauses, in which Kant recurs to the dualism with which he started, cannot hide from us how near he has come to the renunciation of it.

---

[1] Kant, i. 638 (Rosenkranz's edition).

When we regard Kant in this way as asserting from one point of view an absolute limit which from another point of view he permits us to transcend, it becomes obvious that his philosophy is in an unstable equilibrium, which cannot but be disturbed by any one who attempts to develop or even to restate his ideas. Hence we need not wonder that those who take in earnest his denunciations of any attempt to transcend experience generally,—like Professor Huxley,—reject as worthless all Kant's later work; and that, on the other side, those who take in earnest his ideas of freedom, of organic unity, of an intuitive understanding, and of a *summum bonum* in which freedom and necessity meet together, are compelled to break through the arbitrary line which he drew between knowledge and belief. In favour of the former course it is easy in many places to appeal to the letter of Kant. In favour of the latter it need only be pointed out that, in Kant's view, all experience rests upon, or is in its development guided by, those ideas which yet he will not permit us to treat as sources of knowledge. Hence the principles of the *Critique* cannot legitimately be used against metaphysic, except by those who are prepared to admit the ideas of reason, up to the point to which he admits them, as ideas that limit and direct our experience,—while rejecting all use of them to cast light upon that which is beyond experience. In other words, they must maintain the possibility of a purely negative knowledge, of the knowledge of a limit by one who yet cannot go beyond it. They must show how we can have an ideal of knowledge which enables us to criticize experience without enabling us to transform it; they must show how ideas of the supersensible can so far be present to our thought as to make visible the boundaries of the prison of sense in which we are confined, without in any way enabling us to escape from it.

Is this possible? We may gather up the Kantian antithesis in the assertion that experience is the imperfect realization of an ideal of knowledge, derived from reason, with materials, derived from sense and understanding, the nature of which is such that they can never be brought into correspondence with the ideal. But this ideal, in all its three forms, as we have seen, is simply the idea of a pure unity or identity in which all differences are lost or dissolved—whether they be the differences of the inner or of the outer life, or finally the difference of inner and outer, subjective and objective, from each other. Kant's view therefore is, in effect, this, that thought carries with it the consciousness of an identity or unity, to which our actual experience in none of its forms fully corresponds. On the other hand, Kant does not hesitate equally to condemn the identity of thought as "empty" and subjective, because it does not contain in itself nor can evolve from itself the complex matter of experience. But this alternate condemnation of experience as unreal from the point of view of the ideas, and of the ideas as unreal from the point of view of experience, seems to show that *both* are unreal, as being abstract elements, which have no value save in their relation to each other, and which lose all their meaning when separated from the unity to which they belong. According to this view, ideas and experience, noumena and phenomena, if they are opposed, are also necessarily related to each other. If our empirical consciousness of the world of objects in space and time, as determined by the categories, does not correspond to the unity or identity of thought which is our ideal of knowledge, yet that idea of unity or identity is set up by thought in *relation* to experience, and cannot, therefore, be essentially irreconcilable with it. The two terms may be opposed, but their opposition cannot be absolute, seeing that they are in essential relation to each other. It is a great logical error not to discern that a negative relation is still a relation, *i.e.*, that it has a positive unity beyond it. This positive unity may not, indeed, be consciously present to us in our immediate apprehension of the relation in question, but it is necessarily implied in it. Now it is just because, in his separation of noumena and phenomena, Kant omits to note their essential relativity that he is forced to regard the former as a set of abstract identities of which nothing can be known, and the latter as the imperfect products of a synthesis which can never be completed or brought to a true unity. Yet the value of his whole treatment of the ideas of reason in relation to our intellectual and moral experience arises from the fact that in practice he does not hold to this abstract separation of the two elements. Ideas absolutely incommensurable with experience could neither stimulate nor guide our empirical synthesis; they could not even be brought into connexion with it. When, therefore, Kant brings them into this connexion, he necessarily alters their meaning. Hence the pure abstract identity which excludes all difference is changed, in its application, into the idea of an organic unity of which the highest type is found in self-consciousness, with its transparent difference of the subjective and objective self. It would be absurd and meaningless to say that science seeks to reduce experience to an abstract identity, in which there is no difference, unless for this were tacitly substituted what is really an entirely different proposition, that science seeks to find in the infinitely diversified world of space and time that unity in difference of which self-consciousness has in itself the pattern. It is in reference to the former kind of identity—the abstract oneness of formal logic—that Kant proves that it is impossible for experience to be made adequate to ideas But it is only of the latter kind of identity—the oneness of self consciousness—that it can be said that it furnishes a guiding principle to scientific investigation or an ideal of knowledge The same confusion is still more evident in Kant s account of our moral experience, in dealing with which he directly attempts to get synthetic propositions out of the pure identity of reason, in other words, to draw definite moral laws out of the logical principle of non contradiction Whatever success he attains is gained by substituting for the formal principle of *self consistency* the positive idea of *consistency with the self*, and again by conceiving this self as a concrete individual, the member of a society, and so standing in essential relation to other selves The pure abstraction from all the external results of action and from all motives of desire, which at the beginning of the *Metaphysic of Ethics* Kant declares to be essential to morality, is modified and indeed transformed, as we go on, by the admissions that other rational beings are *not* external to us in any sense that excludes their good from being an end of our endeavour, and that the desires are *not* irrational and immoral except in so far as they are directed to the pleasures of the sensuous individual (which in a conscious being they never entirely are) Both in the speculative and in the practical sphere, therefore, the absolute opposition of the ideal or noumenal to the empirical disappears, as soon as Kant attempts to apply it For in both the abstract identity of formal logic, which is really the meaning of the noumenon as absolutely opposed to and incommensurable with experience, gives way to the unity of self consciousness,—a unity which is so far from being *absolutely* opposed to the difference of the empirical consciousness that it necessarily implies it For self consciousness presupposes the consciousness of objects, though it is opposed to that consciousness, it is essentially correlated with it, and therefore its opposition cannot be regarded as absolute or incapable of being transcended

These considerations may throw some light on the relation of the *Analytic* and *Dialectic* of Kant, and on the nature of the opposition of noumenon and phenomenon as it is presented in the latter In the deduction of the categories, Kant pointed out the essential relation of the objective world of experience to what he called the "transcendental unity of apperception i e, he pointed out that the unity of consciousness is implied in all its objects This unity, he further showed, must be conceived as "capable of self consciousness , but it actually becomes conscious of self only in relation, though also in opposition, to the other objects determined by it Now it is this consciousness of itself in opposition to other objects which is the source of Kant s "ideas of reason, of the dissatisfaction of the mind with its empirical knowledge, even in its scientific form, and of the demand for a higher kind of knowledge to which experience is not adequate That a standard is set up for experience by which it is condemned is simply a result of the further development of that unity which is implied in experience—a result of the progress of thought from consciousness to self consciousness, and of the contrast between the former and the latter The problem with which Kant s *Dialectic* attempts to deal, and which it treats as insoluble, is, therefore, simply the problem of *raising consciousness to the form of self consciousness* in other words, of attaining to a knowledge of the world of experience as not merely a "synthetic," and therefore imperfect, unity of things external to each other, but as an organic unity of transparent differences, a self differentiating, self integrating unity, such as seems to be presented to us in pure self consciousness Nor can this problem be regarded as insoluble, for the unity of self consciousness is identical with the unity of consciousness, it is only that unity become self-conscious. Hence the point of view at which consciousness and self-consciousness seem to be absolutely opposed to each other,—the highest point of view which Kant *distinctly* reaches,—can be regarded only as a stage of transition from the point at which their relative difference and opposition is not yet developed to the point at which they are seen to be the factors or elements of a still higher unity

The later philosophy of Germany, from Kant to Hegel, is little more than the development of the idea just stated in its twofold aspect In the first place, it is an attempt to show what is involved in the idea of thought or self consciousness as in itself an organic whole, a many in one, a unity which expresses itself in difference, yet so that the difference remains transparent, and therefore is immediately recognized as expression of the unity In the second place, it is an attempt to bridge over the difference between thought or self consciousness and the external world of experience, and to show that this opposition also is subordinated to a higher unity Or, to put it more directly, the idealistic philosophy of Germany seeks, on the one hand, to develop a logic or metaphysic which bases itself, not, like formal logic, on the idea of bare identity, but on the idea of self consciousness, and, on the other hand, to show, in a philosophy of nature and spirit, how, by means of this logic, the opposition of thought to its object, or of the *a priori* to the *a posteriori* in knowledge, may be transcended In the third and fourth sections of this article something more will be said of the manner in which this task was fulfilled Here only a few words are necessary to sum up the results reached, and to give more distinctness to the new ideal of knowledge which those results suggest We have seen that Kant s critical attitude involved two things —on the one hand, the assertion that the existence we know is necessarily existence for thought, and, on the other hand, the denial that that which exists for our thought is absolute reality, a denial which again involves the presence to our thought of an ideal of knowledge, by which our actual knowledge is condemned This ideal, however, was falsely conceived by Kant as an identity without any difference, and, in this sense, he does not hesitate to apply it even to self consciousness itself For, in a remarkable passage,[1] he attempts to prove that the consciousness of self is not a knowledge of the self, by a simple reference to the duality of the self knowing and the self known, arguing that the ego "stands in its own way, just because it exists only *for itself*, i e, because in knowing itself it presupposes itself Kant evidently thinks that to know the real self it would be necessary to apprehend it in simple identity as purely an object without reference to a subject, or purely a subject without reference to an object Yet to this it seems sufficient to answer that such an object or subject would lose its character as object or subject and become equivalent to mere being in general, and that, as such being is a mere abstraction, to know it cannot be the ideal of knowledge If therefore there be a unity or identity of thought which is not realized in experience, and in reference to which we can regard experience as an imperfect form of knowledge, it cannot be found in this abstract identity of being In truth, as we have seen, it is found in that very idea of self consciousness which Kant is criticizing Just because we are self conscious, and therefore oppose the unity of the conscious self to the manifoldness of the world in space and time, do we seek *in* the world of space and time for a transparent unity which we cannot at first find there But, when this is seen, we find in Kant himself the partial solution of the difficulty.

---

[1] *Kritik*, p 279 (Rosenkranz s edition). *cf* Hegel, [illegible] p [illegible]

Self-consciousness presupposes consciousness; for, while the apprehension of objects in consciousness is possible only in relation to the unity of the self, yet it is only in relation to and distinction from these objects that we are conscious of that unity. Hence the two opposites, self and not self, are bound together, and presuppose a unity which reveals itself in their opposition, and which, when made explicit, must reconcile them. If, therefore, self-consciousness, in its first opposition to consciousness, gives rise to an ideal of knowledge to which our empirical knowledge of objects is inadequate, this arises from the fact that not only empirical knowledge but also the ideal to which it is opposed is imperfect, or that they both point to a unity which is manifested in their difference, and which is capable of containing and resolving it. In other words, the opposition of science to its ideal, which Kant has stated in his *Antinomies*, is not an absolute opposition, but one the origin and end of which can be seen.

This opposition reaches its highest point in the contrast between the transparent unity of self-consciousness, in which the difference of knower and known is evanescent, and the essential manifoldness and self-externality of the world in space, in which the differences seem to be insoluble. We must, indeed, think of self-consciousness as having life in itself and therefore as differentiating itself from itself; but this differentiation is held within the limit of its unity, it is a separation of movements which are separated only as they are united. On the other hand, the world in space presents itself as the sphere of external determination, in which things are primarily disunited and act only as they are acted on from without, and in which this external influence never goes so far as to destroy their reciprocal externality. In this sense it is that the opposition of mind and matter was taken by Descartes, and it is a survival of the same mode of thought that leads many even now to draw absolute lines of division between *a priori* and *a posteriori*, between ideas and facts, between spiritual and natural. Kant and Fichte give a new aspect to the difficulty by showing that the difficulty is one of reconciling consciousness and self-consciousness, and that in consciousness there is already present the unity which is manifested in self-consciousness, as, on the other hand, it is only through consciousness and in opposition to it that self-consciousness is possible. And Fichte made a further step when he attempted to show that the categories and the forms of perception, time and space, which Kant had taken as inexplicable facts, are implied in this contrast of consciousness and self-consciousness. The error that clings to Fichte's speculations is, however, that he treats consciousness merely as a necessary illusion which exists simply with a view to self-consciousness, and hence is led to regard self-consciousness itself—because it is essentially related to this necessary illusion—as a schema or image of an unknowable absolute. In fact, in the end Fichte falls back upon the abstract identity in which Kant had found his noumenon, and so ends his philosophy with mysticism. Even Schelling, though he saw that the absolute unity must be one that transcends the difference of self and not self, did not finally escape the tendency to merge all difference in absolute oneness. On the other hand, it was the endeavour of Hegel to proceed in the opposite way,—not to lose self-consciousness or subjectivity in a mere unity of substance, but rather to show that the absolute substance can be truly defined only as a self-conscious subject. And just because he did this he was prepared to take a further step, and to regard the external world, not as Fichte regarded it, as merely the opposite of spirit, nor as Schelling regarded it, as merely the repetition and co-equal of spirit, but rather as its necessary manifestation or as that in and through which alone it can realize itself. His doctrine therefore might be summed up in two propositions,—first, that the absolute substance is spiritual or self-conscious, and, secondly, that the absolute subject or spirit can be conceived as realizing itself only through that very world of externality which at first appears as its opposite. In both respects Hegel's philosophy reverses the *via negativa* of mysticism, and teaches that it is only through the exhaustion of difference that the unity of science, of which the mind contains in itself the certitude, is to be realized. For mind or spirit, viewed in itself, is conceived as a self-differentiating unity, a unity which exists only through opposition of itself to itself. And it is but a necessary result of such a conception that spirit can fully realize its unity only through a world which in the first instance must present itself as the extreme opposite of spirit. Hence the process of thought in itself, which is exhibited in the logic, ends in the opposition to thought of a world which is its negative counterpart. And the "absolute spirit" of Hegel is thus, not pure self-consciousness, but that more concrete unity of self-consciousness with itself which it attains through and by means of this world.

The effect of this view upon the relation of metaphysic to science, which we are at present considering, is noticeable. It does not, as is often supposed, supersede science by an *a priori* construction of the universe, nor does it leave the results of science unchanged and simply provide for it a deeper foundation. The latter was the point at which Kant and Fichte stopped; for, while they showed the relativity of experience to the principle of self-consciousness, they conceived that the function of metaphysic is completed in showing the phenomenal character of the objects of science, and in reserving a free space beyond the phenomenal world for "God, freedom, and immortality." Schelling, on the other hand, as he did not adopt this merely negative view of the relation of spirit to nature or of *a priori* to empirical truth, was obliged to reinterpret the latter by the former. As, however, he did not recognize any distinctions which were not merely quantitative, he was led to apply the same easy key to every lock, and to think that he had explained all the different forms of existence, organic and inorganic, when he had merely pointed out a certain analogy between them. The metaphysic of Hegel, whatever may be said of the actual philosophy of nature produced by its author, contains no necessity for any such arbitrary procedure. In his *Logic*, indeed, he attempts to give us *in abstracto* the movement of thought in itself, from its simplest determination of being as qualitative or quantitative, through the reflective categories of substance and cause, up to its full consciousness of itself in its organic unity.[1] And in so doing he of course gives us an account of the various categories which science uses in the interpretation of nature. He further attempts to show that the highest categories of science are in themselves imperfect and self-contradictory,—in other words, that they mark a stage of thought which falls short of that unity of being and knowing after which science is striving, and which is the presupposition as well as the goal of all intelligence. But, while he does this, he clearly acknowledges two things,—on the one hand that nature is essentially different from pure self-consciousness, and that therefore logic can never by direct evolution of its categories anticipate the investigations of science, and, in the second place, that the final interpretation of nature through the highest categories presupposes its interpretation by the lower categories, and cannot be directly achieved without it. In other words, science must first determine the laws of nature according to the principles of causality and reciprocity, ere philosophy can be in a position to discover the ultimate meaning of nature by the aid of higher principles. "The philosophy of nature," says Hegel, "takes up the material which physical science by direct dealing with experience has prepared for it at the point to which science has brought it, and again transforms this formed material without going back to experience to verify it. Science must, therefore, work into the hands of philosophy, in order that philosophy in its turn may translate the lower universality of the understanding realized by science into the higher universality of reason, and may show how in the light of this higher universality the intelligible world takes the aspect of a whole which has its necessity in itself. The philosophic way of looking at things is not a capricious attempt, once in a way for a change, to walk upon one's head after one has got tired of walking upon one's feet, or to transform one's work-a-day face by painting it over; but, just because the scientific manner of knowing does not satisfy the whole demand of intelligence, philosophy must supplement it by another manner of knowing."[1]

---

[1] This subject—the progress of thought from lower to higher categories and methods—will be more fully discussed in the third section.

The result then may be briefly expressed thus. Kant and his successors showed the relativity of the object of knowledge to the knowing mind. He thus pointed out that the ordinary consciousness, and even science, are abstract and imperfect modes of knowing, in so far as in their determination of objects they take no account of a factor which is always present, to wit, the knowing subject. For *their* purposes, indeed, this abstraction is justifiable and necessary, for by it they are enabled within their prescribed limits to give a more complete view of these objects in their relation to each other than if the attempt had been made to regard them also in relation to the knowing subject. At the same time the scientific result so arrived at is imperfect and incomplete, and it has to be reconsidered in the light of a philosophy which retracts this provisional abstraction. For it must be remembered that the fact that science looks at things only in their relation to each other, and not to the knowing mind, narrows the points of view or categories under which it is able to regard them, or, in other words, limits the questions which the mind is able to put to nature. Just because science does not treat its objects as essentially related to the mind, it is unable to rise to what Hegel calls the point of view of reason, or of the "notion," *i.e.*, it is obliged to treat objects and their relations merely under a set of categories, the highest of which are those of causality and reciprocity, and it is incapable of attaining to the conception of their organic unity. In other words, it is able to reach only a synthetic unity of given differences, and it cannot discover a principle of unity out of which the differences spring and to which they return. Now philosophy goes beyond science just because, along with the idea of the relativity of things to the mind, it brings in the conception of such a unity. Its highest aim is, therefore, not merely, as Kant still held, to secure a place for the supersensible beyond the region of experience, but to reinterpret experience, in the light of a unity which is presupposed in it, but which cannot be made conscious or explicit until the relation of experience to the thinking self is seen,—the unity of all things with each other and with the mind that knows them.

2. *Relation of Metaphysic to Psychology.*—It has already been shown that the doctrine that the thinking subject is presupposed in all objects of knowledge—or, in other words, that existence means existence for a conscious self—is not to be taken in a psychological sense. The idea that all science is based on psychology, and that, therefore, metaphysic and psychology are identical, cannot be retained by any one who has entered into the full meaning of the Kantian criticism. It is, however, so natural a misinterpretation of it, and it is so much favoured by the letter of the very book in which it was first decisively refuted, that it will be useful to point out more directly the fallacy involved in it, especially as this will place us in a better position to determine the true relation of the two parts of philosophy thus confounded.

The misunderstanding first took a definite form in the introduction to Locke's *Essay*, in which he proposes to provide against any undue application of the intellectual powers of man to problems which are too high for them, by first examining and measuring the powers themselves. Stated in this way, it is obvious that the proposal involves an absurdity; for we have nothing to measure with, except the very powers that are to be measured. To see round our knowledge and find its boundary, we must stand outside of it, and where is such a standing ground to be found? We cannot by knowing prescribe limits to knowledge, or, if we seem to be able to do so, it can only be because we compare our actual knowledge with some idea of knowledge which we presuppose. In this way the ancient sceptics—and modern writers like Sir W. Hamilton and Mr Spencer who have followed them—turned the duality involved in the idea of knowledge against its unity, and argued that, because we cannot know the object except as different from and related to the subject, we cannot know it as it is in itself. Obviously in this argument it is involved that in true or absolute knowledge the object must not be distinguished at all from the subject,—to which the easy answer is that *without* such distinction knowledge would be impossible. The sceptic argument, therefore, lands us in the unhappy case pictured in the German proverb "If water chokes us, what shall we drink?" The object cannot be known if it *is* distinguished from the subject, and it cannot be known if it is *not* distinguished from the subject. Obviously the one objection is as good as the other, and both combined only show that the idea of knowledge involves distinction as well as unity, and unity as well as distinction. The sceptic insists on one of these characteristics to the exclusion of the other, and condemns our actual knowledge because it contains both. In Kant there is undoubtedly some trace of the same fallacy, in so far as the idea by contrast with which he condemns the objects of experience as phenomenal is the idea of an abstract identity without any difference; but we have seen that with him this abstract identity is on the point of passing into an altogether different idea—the idea of self-consciousness as the type of knowledge.

It appears, then, that the idea of measuring our powers before we employ them rests on a paralogism; for what is really meant is that we abstract one of the elements of the idea of knowledge, and then condemn knowledge for having other elements in it. It is possible to criticize and condemn special conceptions as not conforming to our idea of knowledge; but it is not possible to criticize the idea of knowledge itself; all we can do is to explain it. It is possible to see the limited and hypothetical character of certain of our ideas or explanations of things, because we are conscious that in developing them we have left out of account certain elements necessary to the whole truth; but this criticism itself implies, as the standard to which we appeal, a consciousness of truth and reality, a consciousness which we cannot further criticize. Here, therefore, we come upon what must seem to all who think it admissible to question the very possibility of knowledge an inevitable reasoning in a circle. We can answer objections only by means of the very idea which they dispute. But the answer is nevertheless a good one; for the objector also stands within the very circle which he seeks to break, and has no means of breaking it except itself. As soon as he speaks, he can be refuted by his own words; for his doubts also presuppose that unity of the intelligence and the intelligible world which he pretends to deny.

---

[1] Hegel, vii. p. 18.

The error, however, cannot be fully corrected until we consider what gives it plausibility. The confusion of the metaphysical with the psychological problem is due to the fact that the being who is the subject of knowledge, for whom all exists that does exist, appears to be one, and only one, of the many objects of knowledge. When we say that existence means only an existence for a thinking self, we seem to be identifying the whole world with the feelings and ideas of men, i.e., with certain phenomena that belong to the life of a class of beings which only forms a part of that world,—phenomena, moreover, that are not exactly the same in any two of that class of beings. If we are to escape this difficulty it is obvious that we must be able to separate the conscious self or subject, as it is implied in all knowledge, from the nature of man as a being who "though formally self-conscious" is yet "part of this partial world," i.e., one of the objects which we know along with and in distinction from other objects, and in whom "the self-consciousness which is in itself complete, and which in its completeness includes the world as its object," is only progressively realized.[1] Metaphysic has to deal with conditions of the knowable, and hence with self-consciousness as that unity which is implied in all that is and is known. Psychology has to inquire how this self-consciousness is realized or developed in man, in whom the consciousness of self grows with the consciousness of a world in space and time, of which he individually is only a part, and to parts of which only he stands in immediate relation. In considering the former question we are considering the sphere within which all knowledge and all objects of knowledge are contained. In considering the latter we are selecting one particular object or class of objects within this sphere,—although no doubt it must make a great difference in our treatment of this object that we have to consider it as existing not only for us but for itself. If nature "becomes self-conscious in man," it is impossible to treat man *merely* as one among the other objects of nature. But it is not less true that he *is* one of those objects, and, in this point of view, the department of science and philosophy that deals with his life is as distinct from metaphysic—which deals with the conditions of all knowing and being—as is astronomy or physics. In both cases we have before us objects which we may consider in themselves apart from their relations to the conscious subject, and in both cases we must take cognizance of these relations if we would have a complete and final view of those objects. It is possible to have a purely objective anthropology or psychology—which abstracts from the relation of man to the mind that knows him—just as it is possible to have a purely objective science of nature. Such a natural science of man, however, will necessarily abstract at the same time from the fact that in man is manifested that universal principle in relation to which all things are and are known. In other words, it will omit that distinctive characteristic of man's being in virtue of which he is a subject of knowledge and a moral agent. Hence the abstraction in this case is more likely to lead to positive error, more likely to produce not only an imperfect but a distorted view of the object. Inorganic nature, if we take it *in itself*, is not untruly viewed, under the categories of causality and reciprocity, as a collection of objects externally determined by each other; the error lies only in taking it as if it could exist in itself. Even organic beings do not suffer much injustice in being brought under such categories; for, though, as living and still more as sensitive beings, they involve in themselves and in their relation to the world a kind of unity of differences to which the categories of external relation imperfectly correspond, yet they are not such unities *for themselves*, but only *for us*. In other words, the principle through which they are and are known is still external to them. Hence also they are determined by outward influences, though these influences act rather as stimuli to what we may call the self-determined movement of their own life than as mechanical or chemical forces which change it. But in man, in so far as he is self-conscious,—and it is self-consciousness that makes him man,—the unity through which all things are and are known is manifested; and therefore he is emancipated, or at least is continually emancipating himself, from the law of external influence. Nature and necessity exist for him as that from which his life starts, in relation to which he becomes conscious of himself, against which he has to assert himself, and in the complete overcoming of which lies the end of all his endeavour. Nature is the negative rather than the positive starting point of his existence, the presupposition against which he reacts rather than that on which he proceeds; and, therefore, to treat him simply as a natural being is even more inaccurate and misleading than to forget or deny his relation to nature altogether. A true psychology must, however, avoid both errors: it must conceive man as at once spiritual and natural; it must find a reconciliation of freedom and necessity. It must face all the difficulties involved in the conception of the absolute principle of self-consciousness,—through which all things are and are known,—as manifesting itself in the life of a being like man, who "comes to himself" only by a long process of development out of the unconsciousness of a merely animal existence.

This problem first presented itself in a distinct form in the discussions of the Socratic school as to the nature of knowledge, discussions which turn mainly upon the relation of the conscious to the unconscious element in thought. Socrates, by his method more than by any direct statement, drew attention to the fact that all particular judgments in morals involve or presuppose a universal principle. At the same time he pointed out that, so far from this universal principle being known to those who are continually making such judgments, they are not even conscious of its existence. They constantly use general terms whose meaning they have never even thought of defining. The beginning of a rational life for them must therefore lie in their becoming conscious of their ignorance, i.e., conscious that they have been all along judging, and therefore acting, on untested and even unknown assumptions. They must bring the unconscious universal to the light of day and define it, for until that is done it is impossible to live a moral, that is, a rational life. "Virtue is knowledge," i.e., it is acting, not according to opinions, or particular judgments,—whose universal is unknown and which therefore may be regarded as expressing merely the impulses or habits of the individual,—but in view of a universal principle determined by reason.

The onesidedness of this view—which absolutely condemns as vice all virtue that is not based on conscious principle—was partly corrected by another part of the doctrine of Socrates, who taught that knowledge is something that must be evolved from within the mind and not merely communicated to it from without. For this implies that the moral principle may be present in men's minds, and may rule their thoughts and actions, long before they become directly conscious of it. They *are* rational although they have never thought about reason, and they do not wait for scientific ethics to judge and act morally, any more than they wait for logic to reason correctly. It is this line of thought which is universalized and mythically expressed by Plato in his doctrine of "reminiscence." According to this myth, we were conscious of ideas or universals in our pre-natal state, we forgot them in the shock of birth into this mortal life, but in feeling or sharing the rapture of the poet or the lover we recall them as identified or confused with individual objects which "are like them, or partake in them." The same explanation is given of the practical skill of the general and the statesman, and even of the "right opinion" which guides the ordinary good man. Such opinion is neither knowledge nor ignorance: not knowledge, for general principles or ideas are not in it present to the mind *as* ideas, and therefore the particular cannot be distinctly subsumed under them, yet not ignorance, for the ideas are after all present though wrapped up in the particulars or confused with them. Nay, in the *Theætetus*, Plato endeavours to show that the pure particular without the universal, sensations without ideas, cannot enter into our consciousness at all, and that therefore the lowest point to which a conscious being can descend is "opinion," in which particular and universal, sensible and intelligible, are mingled together. In other words, no conscious being can apprehend the particular except through the universal, though that universal may be present only *in* consciousness and not *to* it. The task of philosophy is therefore only to make men "recollect themselves," *i.e.*, to make *self-conscious* that universality of thought in which all rational beings "partake," or which, in the language of later philosophy, constitutes reason. The imperfection of Plato's view lay, however, in this, that, while he clearly recognized that the condition of all consciousness of the particular is the universal, he did not see with equal clearness that the universal has a meaning only in relation to the particular. And this tendency to separate universal from particular is naturally accompanied by a tendency to set the subjective against the objective, and to regard the world, not as the manifestation of reason, but as a dualistic world, in which reason is chained to a lower principle—a world which can at best only give a hint or suggestion to the mind to enable it to recollect itself and recover for itself its own treasures. Thus the false method of introspection, the "high *priori* road" of mysticism, was at least opened up by Plato, if he did not altogether forsake the narrower and harder way to the spiritual world through nature and experience.

---

[1] Hume, vol. i. p. 131 (Green's edition).

The great step in advance taken by Aristotle was due to his seeing the danger of this tendency. Those, however, who have maintained that Aristotle is the great *a posteriori* philosopher,—as Plato is the great *a priori* philosopher,—have entirely mistaken the bearing of Aristotle's criticism of the Platonic theory. As strongly as Plato does Aristotle maintain that reason is δυναμει παντα τὰ νοητα, and that, therefore, the apprehension of truth *by* the mind is not a mere external communication of it *to* the mind, but rather is the mind coming to a consciousness of itself. As firmly as Plato does he declare that truth in its highest form is self-evidencing, *i.e.*, that the principles of science, the laws of nature, when once they have been discovered, are seen to be true by their own light. His statements to this effect have been neglected or explained away, because they were supposed to be inconsistent with his still more frequently reiterated assertions that it is only from experience and by induction that the truth of things can be discovered. Writers of a later day,—who came to Aristotle with an idea of a fixed opposition between *a priori* and *a posteriori*, and who held that the only possible alternatives were *either* to divide knowledge between the two *or* to explain away one of them,—could not comprehend that Aristotle might be in earnest *both* in asserting that knowledge is derived from experience *and* in asserting that it is an apprehension by reason of that which is identical with itself and needs no extraneous evidence. But Aristotle started with no such fixed opposition. On the contrary, any one who reads the last chapter of the *Posterior Analytics* will see that he had no difficulty in maintaining that knowledge begins in the apprehension of τὸ καθ᾽ ἕκαστον in sense perception, and that it proceeds from many perceptions to experience, and from many experiences to science, while at the same time he declared that the principles of science have their evidence in themselves. And the meaning of this declaration is shown in the *De Anima*, where we find him speaking of knowledge as the realization in the "passive reason" of man of an "active reason" which is eternal and unchangeable, and which in the consciousness of itself includes the knowledge of all things. Of this realization, indeed, there is in man only the potentiality or capacity, but just because this is a pure or universal capacity, because, as Aristotle puts it, it has no quality or determination of its own to stand between it and its objects, it is a capacity in which the absolute reason can realize itself, a capacity of knowing all things. Here we have Plato's myth of reminiscence freed from the metaphor of memory, and reduced to scientific terms, for that myth simply meant that the evolution of knowledge is the development of the mind to the consciousness of itself, and of all that is potentially in it. Only, by the combination of this doctrine with the idea of the necessity of induction, Aristotle at the same time guards against the purely subjective interpretation to which in Plato it was liable. For the process by which the mind "comes to itself", is conceived as a process by which at the same time it rises from the particular to the universal, from the γνώριμα ἡμῖν to the γνώριμα ἁπλῶς, from the bare apprehension of the facts of experience to the knowledge of them through their principles or laws.

Yet Aristotle was as little able as Plato to work out fully a theory of the relation between the universal and the individual reason, and the cause of this failure was in both cases substantially the same. In Plato's philosophy, the ideal tended to divorce itself from the phenomenal world in such wise that the latter was regarded only as suggesting or partaking in the former, but not as entirely explicable by it. It was not merely that, to the mind of the individual in its progress, the veil was only gradually lifted from the rationality of the world, but that in the world there was an irrational element from which the mind could save itself only by flight into the region of abstraction. And, though Aristotle by his doctrine of the essential relation of ideas to experience, or of the development of the mind to the acquisition of knowledge of the world, seemed to be on the way to correct this error, yet he too shrinks from regarding the phenomenal world as in itself intelligible. To him also an irrational matter mingles with things, and is in them a source of contingency and imperfection. Chance is not merely the reflexion upon the world of our imperfect knowledge, but a fact of experience, and there is therefore a region in which our best science cannot rise above generality to universality. In this way there remains for Aristotle an absolute *a posteriori*, a reality which cannot be understood, and which we can scarcely conceive as existing at all for the divine intelligence. At this point the Aristotelian philosophy appears to stand between two alternatives, either that, in the sense of pantheism, the finite world and its contingency is an illusion, or that it is contingent only for the growing intelligence of man, which fully understands neither itself nor the world which is its object. Aristotle, however, does not choose either horn of the dilemma, and leaves us therefore with an unresolved dualism between thought and its object; and this again necessarily involves a dualism between the active reason, which, as he asserts, realizes itself in man, and the passive reason which constitutes his nature as a finite being.

In the Middle Ages the Platonic and Aristotelian idea that the apprehension of objective truth is one with the evolution of the mind to self-consciousness seemed to be entirely lost. Knowledge of the finite world was regarded as indifferent, and knowledge of the infinite was conceived to be something given on authority, and in reference to which the mind was confined to an attitude of passive reception or implicit faith. No greater slavery of the spirit can be conceived than that in which even the truths of religion and morality—the truths that regard the inmost life of the spirit itself—were taken as a lesson to be learned by rote from the lips of a teacher. Yet the consciousness that such truth, if it was to be received by the mind, still more if it was to transform the mind, could not be entirely foreign to it, found a voice in the scholastic philosophy. And the compromise or truce between faith and reason expressed in the saying of Anselm *credo ut intelligam*,—according to which reason was to confine itself to the analysis and demonstration of the data received in implicit faith from the church,—prepared the way for the recognition that the two are not essentially at variance. The mind that proceeds from *veneratio* to *delectatio*, from awe and submission to the doctrine to enjoyment and appreciation of it, must already in its awe and submission have the beginnings of an intelligent appreciation. Anselm's saying might be understood simply as meaning that we must have spiritual experience ere we can understand the things of the spirit. And in this sense it was adopted by the Reformers to express an idea almost the opposite of that with which the scholastics had associated it,—the idea that the direct apprehension of spiritual truth as entering into the inner life of the subject, as identified with his very consciousness of self, is the basis of all knowledge of it. In the Protestant church of the period after the Reformation, we find a growing tendency to insist on the subjectivity of religion, in the same exclusive and one-sided way in which the mediæval church had insisted on its objectivity. In some extreme representatives of Protestantism this went so far as to lead to a disregard, almost to a rejection, of all objective doctrine, and a reduction of theology to an account of the religious consciousness. On the other hand, while religion was thus made subjective, science claimed to be purely objective, and the followers of Bacon seemed to adopt towards nature the same attitude of passive receptivity which the mediæval Christian was taught to hold towards the church. While man was to learn everything from himself in religion, he was to learn nothing from himself in science. His aim must be to exclude subjective *idola*, in other words, to accept the facts as they were given, and keep himself out of the way. The inevitable result of this difference of view as to the nature of knowledge in these two different regions was, however, on the one hand a withdrawal of religion from all connexion with finite interests, and, especially from the attempt to connect religious principles with the knowledge of the finite world, and, on the other hand, an increasing tendency in those who represented finite science to regard religion as something merely subjective and even individual, as a feeling which could not be translated into thought or made the basis of any knowledge of the objective world.

The opposite principles of certitude which were thus set up for religious truth and truth of science need only to be brought together and contrasted to betray that they rest upon opposite abstractions, neither of which expresses the complete nature of truth or knowledge. On the one hand the truths of religion were maintained just because they were not, or were not merely, objective, but were capable of being tested by inner experience, and identified with the self-consciousness of the individual. On the other hand the truths of science were maintained because they were not, or were not merely, subjective, but were capable of being verified in objective experience. It was rightly seen on the one side that mere subjective feelings or opinions have no validity for any one but the subject of them, and on the other side that what is merely objective or externally given can have permanent value and interest for the intelligence only as it ceases to be mere isolated and unrelated fact—nay, that, even when science has discovered law and order in nature, it still wants the highest value and interest so long as that law and order are not seen as standing in essential relation to the intelligence itself. The idea of truth or knowledge as that which is at once objective and subjective, as the unity of things with the mind that knows them, enables us to understand the condemnation which the religious mind passed upon a merely external dogma, and even its lack of interest in a science which presented itself as an account of merely objective or external facts. And it enables us also to understand the way in which scientific men insisted upon objective fact as the basis of all knowledge, and the disrespect which they felt for a religion which seemed to admit that it had no such support. What is wanted to clear up the confusion on both sides is the growth of the perception among scientific men that the objectivity which they are seeking cannot be mere objectivity (which would be unmeaning), but an objectivity that stands in essential relation to the intelligence, and, on the other hand, the growth of the perception among religious men that the subjectivity of religion only means that God, who is the objective principle by whom things are, and are known, is spiritual, and can therefore be revealed to the spirit. When these two corrections have been made, it must become obvious that the religious consciousness is not the consciousness of another object than that which is present in finite experience and science, but simply a higher way of knowing the same object. And in this it is also involved that the two ideas of *a priori* and *a posteriori*, of that which is evolved from within and that which is given from without, are not essentially opposed to each other, but that the *a posteriori* is simply the first form of a consciousness which in its ultimate development must become *a priori*.

In that philosophy of compromise which was initiated by Descartes, one part of knowledge was regarded as innate, or developed from within, and another part as empirical, or imparted from without. In the second period of the history of modern philosophy this compromise was broken, and the names of Locke and Leibnitz—though with some hesitation on both sides—represent respectively the theories that all knowledge is *a posteriori* and that all knowledge is *a priori*. The compromise seemed to be renewed with Kant, but the form in which it was renewed pointed, as has been already shown, to something more than a compromise, for his doctrine was that the *a posteriori* element, the facts, exist for us only under *a priori* conditions, or, in other words, that what is usually called *a posteriori* is in part *a priori*. The criticism of this view need not be repeated. It is sufficient here to say that if, as Kant shows, the elements are inseparable or organically united, it is impossible to allege that so much belongs to the one and so much to the other. Furthermore, the consciousness of an essential difference in the elements of knowledge is possible only so far as that difference is transcended by the unity of knowledge. We can distinguish the *a priori* from the *a posteriori* only on condition that we can transcend the distinction, and this means that the distinction itself is not absolute, but that there is a point of view from which the *a posteriori* may be regarded as *a priori*, and that which is given from without to the spirit may be referred to its own self-determined development.

Now it is just here that we come upon the turning point of the philosophical controversy, in the form which it has taken in modern times. The problem may be expressed thus—In what sense can we apply the idea of development to the human spirit? Are we to treat that development as merely a determination from without, or as an evolution from within, or as partly the one and partly the other? In a sense all writers of the present day would admit that this last is the case. For, on the one hand, even the Darwinian theory accounts for development by aid of what we may call the *a priori* tendency of the individual to maintain itself in the struggle for existence, though it supposes that the condition or medium in which the individual is placed determines the direction in which that development proceeds. And on the other hand, no one now would adopt the Leibnitzian theory that the individual is a monad, whose self-development is entirely conditioned by itself in such a sense that all the relations which it has to other existences are merely apparent, and that the coincidence of its life with the life of the world is the result of a pre-established harmony. On both sides, therefore the idea of self-determination would be admitted, though the tendency of the Darwinians would be to regard this self-determination as something merely formal; and on both sides it would also be admitted that the self-determination does not exclude a determination from without, though extreme opponents of Darwin might be inclined to reduce this determination to a mere stimulus or external condition of the development of the nature of the subject to which the stimulus is applied. The question, however, remains whether, after all, this opposition of without and within is an absolute one, or whether there is any point of view from which it may be transcended. To Aristotle it seemed possible to answer this question in the affirmative, because he conceived that the reason of man is a pure or universal δύναμις, the evolution of which to complete self-consciousness is one with the process whereby the objective world comes to be known. Yet, as Aristotle admitted the existence in the world of a material principle which was essentially different from the ideal principle of reason, he was obliged to limit his statement as to the possible unity of the subjective and the objective consciousness, and to say merely that "in things *without matter* the knower is identical with the known." But this would immediately lead to the conclusion that the pure development of reason must be secured by abstraction from all finite and material objects rather than by a thorough comprehension of them. The freedom of the spirit on this theory, must be a negative and not a positive freedom, a freedom won, not by overcoming the world, but by withdrawing ourselves from its influence. It remained, therefore, for modern philosophy to work out the Aristotelian idea that the rational being as such, in spite of its necessary relation to and dependence on an external world, is never in an absolute sense externally determined. And, as we have already seen, the Kantian philosophy brought this problem within the reach of solution, in so far as it showed, first, that objective existence can have no meaning except existence for a thinking self, and, secondly, that existence for a thinking self means existence the consciousness of which is "capable of being combined with the consciousness of self." Add further to these propositions what was shown by Kant's successors, that that only can be combined with the consciousness of self which is essentially related to it, and we arrive at an idealistic theory of the world, which enables us at once to understand the relative value of the distinction between self-determination and determination from without, and at the same time to see that its value is only relative. If it be true that nothing exists which is not a possible object of consciousness, and again that there is no possible object of consciousness which is not essentially related to self-consciousness, then the phenomena of the external world, which at first present themselves under the aspect of contingent facts, must be capable of being ultimately recognized as the manifestation of reason; and the history of the conscious being in his relations with that world is not a struggle between two independent and unrelated forces, but the evolution by antagonism of one spiritual principle. It is, on this view, the same life which within us is striving for development, and which without us conditions that development. And the reason why the two terms, the self and the not-self, thus appear to be independent of each other, or to be brought together only as they externally act or react upon each other, lies in this, that the object is imperfectly known, and the subject is imperfectly self-conscious. This, however, does not make it less true that in self-consciousness is to be found the principle in reference to which the whole process may be explained, and therefore that the self-conscious subject, as such, lives a life which belongs to him, not merely as one object among others, but as having in himself the principle from which the life and being of all proceeds.

From this point of view, as has been already indicated, the relative value of a theory of human development, such as that which might be based on the ideas of Darwin, would not be denied. The conscious being may be regarded simply as an externally determined object, and the incorrectness of this assumption will not entirely destroy the value of the results attained, especially if, as is often the case with those who seek to construct a natural science of man, the assumption itself is not very strictly adhered to, but corrected by the tacit admission of other conceptions somewhat inconsistent with it. But, at the same time, it would require to be pointed out that such a science is necessarily abstract and imperfect, as it omits from its view the central fact in the life of the object of which it treats. It can do nothing to account for man's consciousness, or his capacity of becoming conscious, of the influences by which he is supposed to be determined; or, to put it from the other side, it takes for granted that the objects that influence man are intelligible objects, "capable of being combined with the consciousness of self," without seeing how much is involved in this assumption. Now it is evident that the consciousness of an influence cannot be explained by the influence itself, nor even by that taken together with the nature of the sensitive beings subjected to it. It is evident also that an influence mediated by consciousness is not, strictly speaking, an external influence, but that it is already transformed, and in process of being further transformed, by the development of the self to which it is present. For the dawn of consciousness, in which the external object first comes into existence for us as opposed to the self, is at the same time the beginning of the process by which its externality is negated or overcome. Self-consciousness is that which makes us individuals in a sense in which individuality can be predicated of none but a self-conscious being. For, in determining himself as a self, the individual at the same time excludes from himself every other thing and being, and determines them as external objects. He emancipates himself from the world at the same time that he repels the world from himself. Yet this movement of thought, by which his individuality is constituted, is also that by which he is lifted above mere individuality; for, in becoming conscious of self and not-self in their opposition and relation, he ceases to be simply identified with the one to the exclusion of the other. His finite individuality is regarded by him from a universal point of view, in which it has no less and no more importance than any other individuality, or in which its greater or less importance is determined only by its place in the whole. On this universality of consciousness rests the possibility of science and of morality. For all science is just a contemplation of the world *in ordine ad universum* and not *in ordine ad individuum*, and all morality is just action with a view to an interest which belongs to the agent, not as this individual, but as a member of a greater whole, and ultimately of the absolute whole in which all men and all things are included.

In this nature of the conscious subject lies also the possibility of metaphysic in the sense of Aristotle, as that science which goes back to a πρωτον φυσει, a beginning which is prior to the existence in consciousness of the individual self, and onward to an end in which the divisions of the finite consciousness are transcended,—as including, in short, ontology, or metaphysic in the narrower sense, on the one side, and theology, or the philosophy of religion, on the other. In truth, these two extremes of science are necessarily bound together; we can only go back to the beginning if we can go on to the end; we can only recover the first unity if we can anticipate the last. Or, to free the subject more definitely from the associations of time, we cannot apprehend the unity which is involved or presupposed in all the differences of our conscious life except in so far as we can look at our individual existence from the point of view of the whole to which it belongs. This will become evident if we consider the nature of the limits which have to be transcended by such a science. The individual conscious subject, as he finds himself at first, is but one being in a world that stretches out, apparently without limits, on every side of him. Of the things by which he is immediately surrounded he sees but a small part, and the influences which he receives from them are, as he knows, like the wave that breaks upon a shore from an unknown ocean, only the last partial expression of impulses that come from regions beyond his ken. Again he finds himself as one in a changing series of beings, of which he knows only the last preceding terms, and he is aware that in a few years he, as one of this series, will cease to be. He is thus to himself a definitely limited being, and though his knowledge of himself and his world may be gradually widened so as to reach some little way back into the past, and anticipate a little of the future, or may go outwards in space to embrace a widening circle of existences around him, yet he always stops at a limit, of which he is conscious that it is no absolute limit, but simply an arbitrary halting place where vision grows indistinct and imperfect. When he reflects upon himself from this point of view, he is forced to regard himself as but a fragment, and a fragment of an unknown whole, by which his whole being is determined to be what it is. His highest knowledge seems to be but a consciousness of his ignorance, his highest freedom a determination by motives the ultimate meaning of which is hid from him.

So far there seems to be no room for any metaphysical knowledge, any knowledge of ourselves and our world which is other than relative and *in ordine ad individuum*. But further reflexion shows that in this very consciousness of limit there is implied a consciousness of that which is beyond limit. While we proceed from part to part, beginning with ourselves and our immediate surroundings, and following out lines of connexion that lose themselves in the distance, we are guided by a consciousness of the whole as a unity through which the parts are determined. Nay, it is just the presence of this consciousness that makes us capable of what seems the piecework of our knowledge, in which, by the aid of the principle of causality, we connect particular with particular, and so gradually extend the sphere of light into the encompassing darkness. For that principle simply means that the limited external object does not sufficiently explain to us its own existence, and that therefore we are forced to explain it by a reference to something beyond it. It means, in other words, that we cannot rest in that which is not a self bounded, self determined whole. The application of the category of external determination has therefore an essential reference to the higher category of self-determination. The mere endlessness of space and time has no meaning except in opposition, yet in relation, to the true infinity of which we find the type in self-conscious thought. Or to put it in the Kantian form in which it is already familiar to us, the consciousness of the objective world in space and time stands in essential relation to the unity of self conscious ness. And if when we regard the former exclusively we are forced to view ourselves as insignificant and short sighted finite beings in an infinite universe, when we regard the latter we are enabled to see that in all this universe there is revealed only that spiritual principle which we find also in ourselves. In this way a new light is thrown on our first consciousness of ignorance. The strivings of our reason after knowledge can no longer be regarded as strivings after an unknown goal, but rather after a goal which it has prescribed for itself. The narrow limits of our individual life are not removed, but they cease to be for us the limits of a narrow circle of definition within a formless infinite. They become the limits of a sphere within a sphere, a sphere which is defined by the idea of knowledge or self consciousness itself, and in which therefore however we may wander, we are everywhere at home. In religious language the sphere is not a mere universe but God, who is without us only as He is within us, so that "by the God within we can understand the God without."

Again, as this consciousness takes man beyond his immediate existence, and enables him to determine it in relation to an absolute unity of all things in God, so it enables him to go back to a unity which is behind or prior to that existence. For, if the individual can look at himself as he looks at others, and at others as he looks at himself, *i.e.*, from a point of view which is unaffected by his individuality, and in which that individuality is for him only what it is for impartial reason, he can have nothing in him which binds his consciousness to his individuality as mere individuality; as therefore he can go beyond himself to apprehend the whole in which his individuality has a place, there is nothing to prevent him from going back upon himself, and upon the conditions which are prior to his own individual being. He is not tied to his immediate life, and can go below it just as he can rise above it.

"O God, I think Thy thoughts after Thee," said Kepler. In reading the "thoughts" written in the planetary system, Kepler was discovering the meaning of that which is simpler and more elementary than the existence of man, as a cycle of mechanical relations are simpler and more elementary than self-consciousness. Yet it was a true feeling that led him to connect this descent into the mechanical world with God. For it is only in virtue of the same faculty which enables us to rise to the absolute life which includes and subordinates our own that we can so free us from the image of our own conscious life as to apprehend and fix in thought the simpler relations of purely physical existence. But the same faculty of going back upon ourselves has a still deeper manifestation. Not only can we abstract from ourselves so as to understand the inorganic world, we can also abstract from ourselves so as to understand the conditions which are prior to the thought, and therefore to the existence, of any objective external world at all, the universal conditions of the knowable and therefore also of reality In doing so, to use Hegel s metaphor, which is but an extension of Kepler s, we are "thinking what God thought and was before the creation of the world," *i e*, we are thinking the spiritual unity presupposed in all knowledge, and therefore in all objects of knowledge—the consciousness in relation to which everything is, and is known

3 *The Relation of Logic to Metaphysic*—The ordinary view of logic is based on two presuppositions which tend to separate it almost entirely from metaphysic it is based on the presupposition of an opposition, or at least a merely external relation, between thought and its object, and again of an opposition, or merely external relation, between the form or method and the content or matter of thought The intelligence is regarded as dealing with an object which is given to it externally, and to which, therefore, it can be true only if it leaves it unchanged and introduces into it nothing of its own Truth, to use a well known definition, is the agreement of our conceptions with their objects, and in bringing about this agreement all the concessions must be on the side of thought Conformably to this view, the processes of thought must be purely analytic, *i e*, thought may break up the given idea of the object into its constituent elements, and again out of these elements it may recompose the idea in its unity, but it can add nothing and take nothing away It is like an instrument which alternately dissects a solid mass into smaller parts and again mechanically presses them together, but which never penetrates and dissolves the hard matter, still less fuses it into a new form by bringing it into contact with new chemical elements

This conception, like much of the philosophy of which it is a specimen, is a kind of exaggerated caricature of one aspect of the philosophy of Aristotle Aristotle is the great analytic philosopher He first laid down boundaries in that continuous domain of science which Plato had first surveyed Not that he ever completely lost sight of the unity or continuity of the different sciences which he thus distinguished His unrivalled speculative genius is shown nowhere more clearly than in those not unfrequent utterances of speculative insight into the unity of things different, by which, as at a stroke, he makes his own landmarks and all landmarks to disappear Yet such utterances generally stand by themselves, and do not alter the general analytic spirit of his philosophy They are not so developed as to show distinctly the merely relative character of the divisions and distinctions which are set up, or the limits of the sphere within which they hold good Hence it was easy for minds which possessed something of Aristotle s keenness of understanding without his speculative depth to neglect such expressions, or to explain them away And this process of degradation was the more rapid as the philosophy of Aristotle soon ceased to be studied in his own writings, and became a traditionary possession of the schools In this way we may partly explain how logic came to be regarded by mediæval philosophy as a form of thought which could be altogether separated from the matter and by the application of which that matter could be in no way affected or changed But for such a view, indeed, it is difficult to conceive how the schoolmen could have ventured to apply any logical processes at all to the sacred matter of dogma The idea of externally adding anything to the faith once delivered to the saints was excluded by the principle of authority, and the idea of developing out of that faith anything that was not immediately contained in it had not yet presented itself to any one Hence the business of thought seemed to be purely formal and analytic, and it was only on the plea of its being such that its activity could be tolerated at all Nor was this view of logic at once changed by the revolt against scholasticism The first philosophical exponents of the modern scientific movement, while they rejected the matter of dogma as fictitious, or at least as transcending the sphere of positive knowledge, and while they substituted in its place, as the object of investigation, the facts of experience, did not realize any more than the schoolmen that the form and method of knowledge could be other than analytic of given matter Bacon, their protagonist, was above all solicitous to guard against any subjective *anticipatio naturæ*, nor did he see that the questions which, in his theory of forms, he proposed that science should ask of nature themselves involved any preconceived theory regarding it Conscious, as every true scientific man must be, that the study of nature involves a constant self abnegation, a patient self distrustful course of experiment and observation, he and his followers did not realize the presuppositions that make the inquiry possible, and by which it must be guided Still less did they recognize that the separation between the mind and its object which they took for granted can only be a relative division, *i e*, a division on the basis of a unity, and that therefore the self abnegation of the mind in its investigation of facts cannot be an absolute self abnegation, but is only the first step on the way to the discovery that the facts are intelligible, and so essentially related to the intelligence Hence to them logic still seemed a mere analytic process, the end and aim of which was understood to be that a world, existing in itself out of relation to thought, should be reproduced in a more or less imperfect image *in* thought And, when it came to be suspected by a less naive philosophy of experience that, after all, certain presuppositions, not given in experience itself, were involved in the scientific interpretation of it, various expedients were devised to reduce these presuppositions in an indirect way to empirical truths,—expedients of which Mill s attempt to base the law of causality upon an *inductio per enumerationem simplicem* may be taken as the type

When we go back to Aristotle,—who was the "founder of logic in the sense that he was the first who treated logical method as a separate branch of science,—we find that his division of logic from metaphysic is by no means so definite and complete as it was made by some of his successors The verification of the highest principle of thought, the law of contradiction, is treated by him as the business of metaphysic And, though he separates the idea of truth from the idea of reality, and regards the former as involving a relation of thought to a reality which is determined in itself independent of that relation, yet he does not regard this independence as by any means absolute Truth is defined by him as a connexion or distinction of ideas which *corresponds* to a union or separation of things, but does not necessarily so correspond This definition, however, holds good only in so far as things are not scientifically known, or in so far as things not essentially related are brought together κατὰ συμβεβηκος Where necessity comes in, and is apprehended by reason, the case is different For in that case we have not merely an external synthesis, but an essential identity, *i e*, a unity of elements which can neither be, nor be known, apart from each other In relation to the principles of science, therefore, Aristotle holds that error, *i e*, a connexion of ideas not corresponding to a connexion of things, is impossible, and that the only alternatives are knowledge and ignorance Either we possess the idea or we do not possess it, as Aristotle otherwise expresses it, in thought we are either in contact with the things or not in contact with them, there is no third possibility The meaning of Aristotle becomes clearer when we remember that, according to his view, the intelligence, in apprehending the indivisible unity of elements in the object, is at the same time apprehending the unity of the object with itself. The mind cannot be deceived in regard to that which forms a part of its consciousness of itself. In freeing the essential conception of the object from the contingency of matter, science has freed the object from that which made it foreign to intelligence, and the relation of thought to things ceases to be one of correspondence, and becomes one of identity.

The legitimate inference from this view of the relation of the intelligence to the intelligible world would seem to be that the partial separation of thought from its object and its imperfect correspondence with it is characteristic of our first empirical consciousness of things, and of the progress from that consciousness to science, but that in completed science the division ceases. The *esse* of things is not their *percipi*, but their *intelligi*. But, if this be taken as the truth, then it can no longer be supposed that the process by which scientific knowledge is attained consists simply in an analysis of the object as it is given in immediate perception. On the contrary, it must be held that, if our thought has to submit itself to the object, and to be brought into conformity with it, by a process of induction, it is equally true that in this process the object also must be changed, that it may be brought into conformity with the principle of thought. The genesis of science, according to this view, is not merely an analysis of given facts, but a process of vital transformation by which consciousness on the one side and the object on the other are brought into unity with each other. The idea, indeed, of an empty process, a process in which the activity of the mind is merely formal, is one which will not stand the slightest examination. A mind without categories, if such a thing were conceivable, would have no questions to ask in relation to the object presented to it, and could therefore get no answers. Those who make a pretence of approaching a subject in an absolutely receptive attitude, and without any presuppositions, only show that they are unconscious of the categories by which their thought is ruled, and they will be most slavishly guided by these categories just because they are unconscious of them. The schoolmen, when they applied their logical principles to the matter of Christian dogma, did not recognize that they were doing more than analysing and bringing out clearly the meaning of that dogma. But the effect of their work was to turn the system of divinity into a collection of insoluble puzzles, for the doctrine was a doctrine of reconciliation between divine and human, infinite and finite, universal and particular, and the principle of their method was to treat all these oppositions as absolute. In like manner it might be shown that the analysis of social phenomena which was made in the last century was inadequate and superficial, just because of the latent assumption of individualism on which it proceeded, and that the greater success of writers like Comte and Spencer does not arise merely or mainly from their being more careful observers of the phenomena of social life, but in great part from the fact that, rather by the unconscious movement of opinion than by any distinct metaphysic, their minds have become possessed by more adequate categories.

The idea that the process of thought is merely formal, or analytic of given matter, is, however, an error that has a truth underlying it. This is the truth expressed by Aristotle in his much misunderstood comparison of the intelligence of man to a *tabula rasa*, upon which nothing at first is written, and again in his assertion—already quoted—that the mind is a pure δυναμις, without any distinguishing quality of its own which could prevent it from apprehending the real nature of other things. In other words, self-conscious reason is not a special thing in the world, but the principle through which all things are, and are understood; and hence, as regards the distinction of things from each other, it is in the first instance undetermined and indifferent, and therefore open to be determined in one way or another, according to the object to which it is directed. But this simply means that the conscious subject, as such, is not bound to his own individuality, but can regard things, nay, in a sense, must regard them, from a point of view which is independent of it. This is what makes possible the self-restraint and self-abnegation prescribed to the scientific man, whose whole duty as it is often said, is to keep himself out of the way and let the objects speak, to lay aside all subjective *idola* and prejudices that stand between him and the reality of things. This at first sight may seem to be equivalent to the assertion that the mind ought to be in a state of simple passivity or receptivity towards objects. What is really meant, however, is not that the intelligence should go out of itself, or cease to be itself, that it may know its object, but simply that it should show itself in its universality, or freedom from the limits of the individual nature. The self-abnegation of science is an endeavour, so to speak, to see the object with its own eyes, but this it can do only in so far as the consciousness for which the object is is that consciousness in relation to which alone all objects are, and are understood. Or, to put it in another form, the conscious self in its scientific self-abnegation does not give itself up to another, and become purely passive; it only gives up all activity which is not the activity of that universal thought for which and through which all things are. Hence, when it has so abnegated itself, its most intense constructive activity is just beginning, though, just so far as the self-abnegation has been real, that constructive activity has become one with the self-revelation of the object. As, however, it is only through the constructive activity of thought that there exists for us any object at all, so it is only through its continued activity that the conception of the object is changed, till it is completely revealed and known. And this activity involves a continuous synthesis, by which an ever wider range of facts is brought together in an ever more definite unity, until the mind has, if we may use the expression, exhausted its store of categories upon the world, and until the world has completely revealed itself in its unity with itself and with the mind.

To combine these two ideas—on the one hand that science begins in a self-abnegation by which the mind renounces all subjective prejudices, and thereby attains a purely objective attitude and on the other hand that this purely objective attitude is not a mere attitude of reception, but one in which the mind is continually transforming the object by its own categories—to see that the universality of the mind in knowing is not mere emptiness, and that its activity is synthetic just when it is most free from all presuppositions extraneous to the nature of its object,—is one of the greatest difficulties of the student of metaphysic. Universality at first looks so like emptiness, and a universal activity so like a merely formal activity, that it is no wonder that the one should be mistaken for the other. But if we make such a confusion, we may soon be forced to choose between a sensationalism that makes knowledge impossible and a mysticism which makes it empty. The pure identity of thought with itself which is involved in the process of analysis is put on the one side and the manifold matter of experience which is the object of thought on the other, and between these opposites no mediation is possible. If we take our stand upon the latter, we are forced to reject all mental synthesis as invalid, because it involves a subjective addition to the facts, if we take our stand on the former, we are compelled to regard all objective experience as irrational, because it does not correspond to the pure identity of thought

In Aristotle's view of logic it cannot be said that this difficulty is clearly solved, though he seems to have seen the error of both extremes On the one hand he often recognizes the synthetic character of the process of induction, as when he speaks of the universal idea or law as a central principle, in which we must find the key to all the difficulties suggested by different aspects of a given subject Yet in other places we trace the influence of a merely analytic conception of that process as a process in which the universal is to be reached by abstracting from the peculiarities of individuals And this conception of it is favoured by Aristotle's metaphysical theory, according to which the forms of things in the finite world are manifested in a resisting matter, a matter which prevents them from being perfectly or universally realized For, in so far as this is the case, the facts will not be entirely explained by the knowledge of the form, and the knowledge of the form must be obtained, not by combining all the facts, but rather by abstracting from them Again, in Aristotle's account of the process of thought in the *Prior Analytics*, he regards it as a formal deductive process, and, though in the *Posterior Analytics* he attempts to give a synthetic meaning to the syllogism by treating it as the method in which the properties of a thing may be proved of it, or combined with it, through its essential definition yet this adventitious meaning bestowed upon the syllogistic process does not alter its essential nature The ultimate source of this inadequate view of the process of thought seems to lie in Aristotle's imperfect conception of the unity or identity which is for him the type of knowledge For, though, both in the *Metaphysic* and the *De Anima*, he defines that identity as self consciousness or as a consciousness of objects which is identical with self consciousness, yet he does not seem clearly to distinguish between a unity in which there is no difference and a unity in which difference is transcended and reconciled This seems to be shown by his description of the principles which reason apprehends as *individua* or indivisible unities, rather than unities which imply, while they transcend, difference Yet, in this definition of the unity of knowledge as self consciousness, Aristotle has implicitly admitted that there is a duality or difference in the unity itself, and this might have been expected to modify his conception of the relation of consciousness to its objects For, as self consciousness is not simple like a chemical element, but only in the sense that it is an indissoluble unity of opposites, it might have been anticipated that one who had realized self consciousness as the principle of knowledge would be able to regard the opposition between the consciousness of self and the consciousness of the world as itself also capable of being conceived as a unity

This misconception of Aristotle may be shown in another way In the *Metaphysic* we find him laying down what is called the logical law of contradiction as the ultimate principle of knowledge The meaning of this principle, however, as Aristotle states it, is simply that thought in its essence is definition or distinction If, as Heraclitus says, everything at once is and is not, if we cannot attach any definite predicates to things by which they may be distinguished from each other, then, as Aristotle argues, thought is chaos, and knowledge is impossible If determination be not negation, if the assertion of A be not the negation of not-A, then there is no meaning in words The criticism to be made on this view is obviously, not that it is a false statement of the law of thought, but that it is an imperfect statement of it. Thought is undoubtedly distinction, and, if all distinction be confounded, no meaning can be apprehended or expressed But thought is also relation and connexion of the things distinguished, and this aspect of it is equally important with the other Aristotle shows his one sidedness—a one sidedness which throws him into opposition to Plato, but which enables him to correct Plato only by falling into the opposite error—when he exclusively fixes his attention on the "differentiating" aspect of knowledge, and takes no notice of the "integrating' aspect of it It is easy to see that this exclusive attention to one side of the truth may lead in many ways to a distorted view both of the world and of the intelligence that apprehends it If Heraclitus be interpreted as simply denying the right of thought to introduce its definiteness into the flux of sense, nothing but absolute scepticism can come out of his philosophy, and Aristotle was right in maintaining that it is only as the flux is brought to a stand, and the universal is fixed as a permanent and definite object of thought,[1] that knowledge becomes possible But, on the other hand, if distinction be taken as absolute, if the definite assertion of a thing be taken as a negation of all relation to what it is not, if the fixity of thought be taken as an abstract self identity which excludes all the movement of finite things wherein they show their finitude and pass beyond themselves into other things, then knowledge will be equally impossible Our consciousness, on such a theory, would be disintegrated into parts which would own no connexion with each other, nor would it be possible for us to think of things as, in spite of their differences, bound together into the unity of one world The law of contradiction or distinction, therefore, is likely to lead to serious misconceptions, unless it be complemented by a law of relation—a law expressing the truth that there is a unity which transcends all distinction For all intelligible distinction —all distinction of things in the intelligible world—must be subordinate to their unity as belonging to that world, and therefore essentially connected with each other and with the intelligence In such a world, in other words, there can be no absolute distinctions or differences (not even between being and not being), for distinction without relation is impossible, and a conception held in absolute isolation from all correlated conceptions ceases to have any meaning This does not, of course, imply a negation of the law of contradiction within its own sphere, but it does imply that that sphere is limited, and that there is no absolute contradiction All opposition is within a presupposed unity, and therefore points to a higher reconciliation, a reconciliation which is reached when we show that the opposition is one of correlative elements

The great step in logical theory which was taken by the idealistic philosophy of the post-Kantian period was simply to dissipate the confusion which had prevailed so long between that bare or formal identity, which is but the beginning of thought and knowledge, and that concrete unity of difference, which is its highest idea and end It was, in other words, to correct and complete the conceptions of thought as analytical, and as externally synthetical, by the conception of it as self-determining, to show that it is a unity which manifests itself in difference and opposition, yet in all this, even when it seems to be dealing with an object which is altogether external to it, is really developing and revealing itself This new movement of thought might, in one point of view, be described as the addition of another logic to the logic of analysis and the logic of inductive synthesis which were already in existence But it was really more than this, for the new logic was not merely an external addition to the old logics, it also put a new meaning into these logics by bringing to light the principles that were involved in them At the same time it broke down the division that had been supposed to exist between logic and metaphysic, between the form or method of thought and its matter It showed that thought itself contains a matter from which it cannot be separated, and that it is only by reason of this matter that it is able to ask intelligent questions of nature, and to get from nature intelligible answers A short space must be devoted to explain this relation of the three logics to each other

---

[1] *ἠρεμήσαντος τοῦ καθόλου ἐν τῇ ψυχῇ*, *An Post*, ii. 19.

The analytic logic fairly represents our first scientific attitude to the world, in which we concentrate our attention upon the facts as they are given in experience, with no thought of any mental synthesis through which they are given To ourselves we seem to have to do with an object which is altogether independent of our thought, and what we need in order to know it is to keep ourselves in a purely receptive attitude All we can do is to analyse what is given, without adding anything of our own to it It has, however, already been pointed out that this apparent self abnegation is possible only because, in abnegating our individual point of view, we do not abnegate the point of view that belongs to us as universal or thinking subjects In other words, the objectivity of knowledge thus attained is not the ceasing of the activity of our thought, but rather of all that interferes with that activity We seem to abstract from ourselves, but what we do abstract from is only the individuality that stands between us and the world The scientific observer who has thus denied himself, however, is not necessarily conscious of the meaning of what he has done The immediate expression of his consciousness is not "I think the object," but "it, the object, is', and the more intensely active he is the more his activity is lost for him in the object of it His whole work is, for himself, only the analysis of given facts, and for the rest he seems to have nothing to do but to take the world as he finds it The voice of nature to which he listens is for him not his own voice but the voice of a stranger, and it does not occur to him to reflect that nature could not speak to any one but a conscious self His business is to determine things as they present themselves, to enumerate their qualities to measure their quantities, and his logic accordingly is a logic governed by the idea of the relative comprehension and extension of the things which he thus names and classifies Such an analytic logic seems to be all that is necessary, because the only predicates by which things are as yet determined are those which are involved in their presence to us in perception, and as perceived they seem to be at once given in all their reality to the mind that apprehends them

A step is taken beyond this first naive consciousness of things, whenever a distinction is made between appearance and reality, or whenever it is seen that the things perceived are essentially related to each other, and that therefore they cannot be known by their immediate presence to sense, but only by a mind which relates that which is, to that which is not, immediately perceived If "the shows of things are least themselves," we must go beyond the shows in order to know them, we must seek out the permanent for that which is given as transient, the law for the phenomenon, the cause for the effect. The process of thought in knowledge therefore is no longer lost in its immediate object, but is, partly at least, distinguished from it For just in proportion as the reality is separated from the appearance does the knower become conscious of an activity of his own thought in determining things From this point of view nature is no longer an object which spontaneously reveals itself to us, but rather one which hides its meaning from us, and out of which we must wring its secret by persistent questioning And, as this questioning process obviously has not its direction determined purely by the object itself, it becomes manifest that the mind must bring with it the categories by which it seeks to make nature intelligible To ask for the causes of things, or the laws of things, presupposes that the immediate appearance of them does not correspond to an idea of reality which the mind brings with it, and by which it judges the appearance Nature is supposed to be given to or perceived by us as a multitude of objects in space passing through successive changes in time, and what science seeks is to discover a necessity of connexion running through all this apparently contingent coexistence and succession and binding it into a system Science, therefore, seems to question nature by means of an idea of the necessary interdependence and connexion of all things, as parts of one systematic whole governed by general laws—an idea which it does not get from nature, but which it brings to nature Hence the logic in which this process of investigation expresses its consciousness of itself will be a synthetic logic, a logic built on certain principles which are conceived to be independent of experience, and by the aid of which we may so transform that experience, so penetrate into it or get beyond it, as to find for it a better explanation than that which it immediately gives of itself The *Posterior Analytic*, in which Aristotle brings in the idea of cause to vivify the syllogistic process, or supply a real meaning to it, may already be regarded as a first essay in this direction And the theory of inductive logic, as explained by Bacon and his successors down to Mill, is a continuous attempt to determine what are the principles and methods on which experience must be questioned, in order to extract from it a knowledge which is not given in immediate perception

It was, however, Hume who first brought into a clear light the subjectivity of the principles postulated in this logic, and especially of the principle of causality, which is the most important of them In thus contrasting the subjectivity of the principles of science with the objectivity of the facts to which they are applied, it was his intention to cast doubt on the science which is based on the application of the former to the latter The principles, he maintains, are not legitimately derived from the facts, therefore they cannot legitimately be used to interpret them. They are due to the influence of habit, which by an illegitimate process raises frequency of occurrence into the universality and necessity of law, and so changes a mere subjective association of ideas into an assured belief and expectation of objective facts The answer given by Kant to this sceptical criticism of science involved a rejection of that very opposition of subjective and objective upon which it was based Without necessary and universal principles, the experience of things as qualitatively and quantitatively determined objects, coexisting in space and passing through changes in time (or even the determination of the successive states of the subject as successive), would itself have been impossible Hence necessity of thought cannot be derived from a frequent experience of such objects. It is true that the determination of things as permanent substances reciprocally acting on each other, according to universal laws, goes beyond the determination of them as qualified and quantified phenomena in space and time But both determinations are possible only through the same *a priori* principle, and we cannot admit the former determination without implicitly admitting the latter As, therefore, it is through the necessity and universality of thought that objects exist for us, even before the application to them of the principles of scientific induction, and as the application of those principles is only a further step in that *a priori* synthesis which is already involved in the perception of these objects, we have no reason for treating the former kind of synthesis as objectively valid which does not equally apply to the latter.

This vindication of the principles of induction has, however, a further consequence, which was not clearly seen by Kant. It is fatal to the antithesis of the "given" and the "known," of what is perceived and what is conceived, of *natura materialiter spectata* and *natura formaliter spectata*, which he still admitted. For that antithesis really rested on the idea that there is no universal and necessary principle of determination of things involved in the apprehension of them as qualified and quantified phenomena in space and time. So soon, therefore as it is seen that there is such a principle, and that the first determination of things as objects of perception is due to the same *a priori* synthesis which determines them in the second place as objects of experience, the ground for that contrast between reality and appearance on which the theory of induction rested is taken away. Kant, indeed, finds a new meaning for that contrast by interpreting it as referring, not to the opposition between things as they are given and things as they are known, but to a supposed opposition between things as they are given and known in experience and things as they are in themselves out of experience. This new antithesis of reality and appearance, however, only means that the former antithesis has broken down, and that therefore the ideal of knowledge based upon it has yielded to a new ideal. The so called things in themselves are noumena, the objects of an intuitive or perceptive understanding, *i.e.*, objects in which the contrast of perception and conception, of given and known, is transcended. We can make Kant's theory consistent only by supposing him to mean that the conception of the world as a system of substances determining each other according to universal laws does not yet satisfy the idea of knowledge which reason brings with it. In other words, just as science from the point of view of necessary law found something wanting in the conception of the world as a mere complex of quantified and qualified phenomena in space and time, so philosophy, in view of a still higher ideal of knowledge, may condemn the conception of the world as a system of objects determined by necessary laws of relation as itself inadequate and imperfect. And we have seen that this higher ideal is that which is involved in the unity of self consciousness. Unfortunately Kant was unable, as Aristotle had been unable, to distinguish this idea from the idea of an abstract identity in which there is no room for even a relative difference of perception and conception, and therefore the perceptive understanding was named by him only to be rejected.

If, however, we correct this inadequacy of Kant's statement, as his later works enable us partly to correct it, we see that it involves a new idea of knowledge and a new logic,—a logic governed by the idea of organic unity and development, just as the analytic logic had been governed by the idea of identity, and as the inductive logic had been governed by the idea of necessary law. For if the unity of self-consciousness be our type of knowledge truth must mean to us, not the apprehension of objects as self identical things, distinguished from each other in quantity and quality, nor even the determination of such things as standing in necessary relations to each other. It must mean the determination of the world (and of whatever in it is in any sense an independent reality so far as it is so independent) as a unity which realizes itself in and through difference, a unity which is indeed determined, but determined by itself. In a view of the world which is governed by this category, correlation must be reinterpreted as organic unity, and causation as development. Its logical method must be neither analytical nor synthetical, or rather it must be both at once, *i.e.*, it must endeavour to exhibit the process of things as the evolution of a unity which is at once self-differentiating and self-integrating, which manifests itself in difference, that through difference it may return upon itself. Further, as this logic arises simply out of a deeper consciousness of that which was contained in the two previous logics, so it first enables us to explain them. In other words, the advance from the analytic to the inductive logic, and again from the inductive to what may be called the genetic logic, may itself be shown to be a self determined development of thought, in which the first two steps are the imperfect manifestation of a principle fully revealed only in the last step. The consciousness of self identical objects, independent of each other and of thought, is thus only the beginning of a process of knowledge which reaches its second stage in the determination of these objects as essentially related to each other, and which finds its ultimate end in the knowledge of the correlated objects as essentially related to the mind that knows them. Or if, in this last point of view, things are still conceived as having a certain relative independence of the mind, it can only be in so far as they are in the Leibnitzian sense monads, or microcosms,—*i.e.*, in so far as they are self-determined, and so have, in the narrower circle of their individual life, something analogous to the self completed nature of the world, when it is contemplated in its unity with its spiritual principle.

Such a genetic logic is inconsistent with any absolute distinction between the *a priori* and *a posteriori* element in knowledge. For here the *a priori* is not simply a law of necessary connexion to be applied to an external matter, but a principle of organic development, a principle which, from the very nature of it, cannot be applied to a foreign matter. To treat the world as organic is to apply to it a category which is inconsistent with its being something merely given or externally presented to thought. The relation of things to thought must itself be brought under the same category of organic unity which is applied to the relation of things to each other in the world, otherwise the externality of the world to the thought for which it is will contradict the conception of the world as itself organic. Hence the distinction of *a priori* and *a posteriori*, so far as it is maintained at all, must shrink to something secondary and relative. It can be maintained only as a distinction of thought from its object, which presupposes their ultimate unity. From this point of view logic may be said to deal with the *a priori*, in so far as it treats the general conditions and methods of knowledge without reference to any particular object. Logic must exhibit abstractly the process by which the intelligence establishes its unity with the intelligible world, or, to put it in another way, it must demonstrate that the being of things can be truly conceived only as their being for thought. It is limited to the *a priori*, in the sense that it ends with the idea that the *esse* of things is their *intelligi*, and does not consider how this real intelligence or intelligible reality manifests itself in the concrete world of nature and spirit.

In this sense logic cannot be separated from metaphysic if metaphysic be confined to ontology. They are simply two aspects of one science, which we may regard either as determining the idea of being or the idea of knowing. The process of knowing is never really a formal process, it always involves the application of certain categories, and these categories are simply successive definitions of being or reality. We cannot separate the category from the movement of thought by which it is evolved and applied, nor the transition from lower to higher categories from changes of logical method. Hence a logic divorced from metaphysic inevitably becomes empty and unreal, and a metaphysic divorced from logic reduces itself to a kind of dictionary of abstract terms, which are put in no living relation to each other For such a logic and such a metaphysic must rest on the assumption of an absolute division between being and thought, the very two terms the unity of which it must be the utmost object of both logic and metaphysic to prove and to produce

4 *The Relation of Metaphysic to Philosophy of Religion* —The possibility of a "first philosophy,' as we have already seen, is essentially bound up with the possibility of what we may call a last philosophy It is only in so far as we can rise above the point of view of the individual and the dualism of the ordinary consciousness—in so far, in other words, as we can have at least an anticipative consciousness of that last unity in which all the differences of things from each other and from the mind that knows them are explained and transcended—that we are able to go back to that first unity which all these differences presuppose The life of man begins with a divided consciousness, with a consciousness of self which is opposed to the consciousness of what is not-self, with a consciousness of a multiplicity of particulars which do not seem to be bound together by any one universal principle Such division and apparent independence of what are really parts of one whole is characteristic of nature, and in spirit it is at first only so far transcended that it has become conscious of itself A conscious difference, however, as it is a difference in consciousness, is no longer an unmediated difference It is a difference through which the unity has begun to show itself, and which therefore the unity is on the way to subordinate And all the development of consciousness and self consciousness is just the process through which this subordination is carried out, up to the point at which the difference is seen to be nothing but the manifestation of the unity Just so far therefore, as this end is present to us,—so far as we are able to look forward to the solution or reconciliation of all the divisions and oppositions of which we are conscious and to see that there is an all-embracing unity which they cannot destroy,—is it possible that we should look back to the beginning or first unity, and recognize that these divisions and oppositions are but the manifestations of it Thus the extremes of abstractness and of concreteness of thought are bound up together The freedom of intelligence by which we get rid of the complexity of our actual life, and direct our thoughts to the simplest and most elementary conditions of being and knowing, is possible only to those who are not limited to that life, but can regard it and all its finite concerns from the point of view of the infinite and the universal In this sense it is true that religion and metaphysic spring from the same source, and that it is possible to vindicate the rationality of religion only on metaphysical principles The philosophy of religion is, in fact, only the last application or final expression of metaphysic, and, conversely, a metaphysic which is not capable of furnishing an explanation of religion contradicts itself

This last remark affords us a kind of criterion of a true metaphysic Can it or can it not explain religion? If it cannot, it must be equally unable to explain its own possibility, and therefore implicitly it condemns itself Thus a pantheistic system, which loses the subject in the absolute substance, cannot explain how that subject should apprehend the substance of which it is but a transitory mode, nor, on the other hand, can it explain why the substance should manifest itself in and to a subject And the same criticism may be made on all theories in which the first or metaphysical unity is abstractly opposed to the manifoldness and contingency of things Not only of Spinoza, but also of Kant, of Fichte, and even of Schelling, it might with some truth be said that their absolute is like the lion's den, towards which all the tracks are directed, while none come from it. It is essential that the first unity should be such as to explain the possibility of difference and division, for, if it is not, then the return to unity out of difference is made as accidental as the difference itself When Aristotle represented the Divine Being as pure self-consciousness, pure form without matter, he found himself unable to account for the existence of any world in which form was realized in matter When therefore he speaks of the process of the finite world by which it returns to God, and attributes to nature a will, which is directed to the good as its final cause, his theory seems to be little more than a metaphor in which the analogy of consciousness is applied to the unconscious For, if the Divine Being is not manifested in the world, any tendency of the world to realize the good becomes an inexplicable fact A similar difficulty is, as we saw, involved in Kant s confusion of the bare identity of understanding with the absolute unity of knowledge Reducing the unity of self consciousness to such a bare identity, Kant could not be expected to see, what Aristotle had not seen, that pure self-consciousness is essentially related to anything but itself Hence the various attempts which he made in his ethical works and in his *Criticism of Judgment* to find a link of connexion between the noumenal and the empirical were necessarily condemned even by himself as the expressions of a merely regulative and subjective principle of knowledge Even Fichte, who found in the thought, which is for him the *prius* of all existence, a principle of differentiation and integration which explained how self-consciousness in us should be necessarily correlative with the consciousness of a world, was unable to free himself from the Kantian opposition of a noumenal identity in which there is no difference to a phenomenal unity which is realized in difference Hence by him also the return out of difference is regarded as an impossibility, or as a *processus in infinitum*, and the absolute unity as that which is beyond all knowledge and only apprehended by faith

If we look to completely elaborated theories, and disregard all tentative and imperfect sketches, it may fairly be said that all that has as yet been done in the region of pure metaphysic is contained in two works, in the *Metaphysic* of Aristotle and the *Logic* of Hegel And up to a certain point the lesson which they teach is one and the same, viz , that the ultimate unity which is presupposed in all differences is the unity of thought with itself, the unity of self consciousness, and that in this unity is contained the type of all science, and the form of all existence , in other words, I = I is the formula of the universe The difference between these two works has, however, already been indicated With Aristotle, because he neglects the essential relation of self consciousness to consciousness, or of the conscious self to the world of objects in space and time, the unity of self consciousness tends to pass, as it did pass with the Neo Platonists, into a pure identity without difference In the Hegelian logic, on the other hand, self-consciousness is interpreted as a unity which realizes itself through difference and the reconciliation of difference—as, in fact, an organic unity of elements, which exist only as they pass into each other In other words, it is shown that the differentiating movement by which the subjective and the objective self are opposed and the integrating movement by which they are reunited are both essential Hence we cannot think of the conscious self as a simple resting identity, but only as an active self-determining principle , nor can we think of its self-determination as a pure affirmation of itself, without any negation, but only as an affirmation which involves a double negation—an opposition of two elements which yet are essentially united. Each factor in this unity, in fact, is necessarily conceived as passing beyond itself into the other , the subject is subject only as it relates itself to the object, the object is object only as it relates itself to the subject. It is this tension against each other of elements which yet are correlated and indissolubly united, this self-surrender to each other of elements which yet are maintained in their distinction, which constitutes the organic unity of thought in itself, and separates it from the mere abstract unity of mysticism. When, however, the concrete or self-differentiating character of the unity of self-consciousness is apprehended in this way,—so that it is impossible to confuse its indivisible unity with the simplicity of that which is one merely because it has no differences in it,—the problem of the relation of pure self-consciousness to the world in space and time ceases to be insoluble. Thought, as it is seen to have difference in itself, is no longer irreconcilable with the world of difference; nor is it necessary to introduce a foreign ὕλη to make their connexion intelligible. For, as thought is a principle of difference as well as of unity, of analysis as well as of synthesis, and as it cannot realize itself in its unity except through the utmost development of difference, abstract self-consciousness, with its transparent or merely ideal difference, cannot be its ultimate form. On the contrary, the consciousness of self is possible only in distinction from, and in relation to, a world of objects. In other words, the unity of the thinking subject presupposes, not merely the opposition of the subjective and the objective self, but also the opposition of the self in its pure self-identity to a world of externality and difference. The pure intelligence, which is the *prius* of all things, must not, therefore, be regarded—as Aristotle regarded it—as merely theoretical, but also as practical. It must be conceived as a living principle, a principle which only in self-manifestation can be conscious of itself, and to the very nature of which, therefore, self-manifestation is essential. In this way Hegel—just because he grasped the concrete character of the unity of thought in itself—was enabled to understand the necessary unity of thought or self-consciousness with the world, and to heal the division of physics from metaphysic, which Aristotle had admitted.

Schelling and others who have raised objections to the Hegelian method have specially directed their criticisms against this transition from logic to the philosophy of nature, from pure self-consciousness to the external world in space and time. In doing so, they have practically fallen back upon the Aristotelian theory, with its opposition of God, as pure form, to the finite world. But this in effect is to deny that "the real is the rational" or intelligible, and to introduce into the world, as the ground of its distinction from reason, a purely irrational or contingent element. A modern follower of Schelling's later positive philosophy only draws the necessary consequence from this view when he teaches the pessimist creed that the highest good is the negation or extinction of the finite. Nor can we wonder that the same writer who denies that the absolute self-consciousness is essentially related to or manifested in the world should proceed to reduce this self-consciousness to a mystic identity which comes out of itself and becomes self-conscious only by an inscrutable act of will. The fact, indeed, that those who deny the possibility of a rational transition from self-consciousness to the world are forced by the logic of their position to reduce self-consciousness to an abstract identity may be regarded as a kind of indirect proof that the principle of self-consciousness, truly conceived, does involve that transition. Another step in the same direction may be made if we consider how the Cartesian philosophy treated the same opposition, which it also regarded as absolute. By Descartes mind and matter, thought and extension, are defined as abstract opposites, every quality of each finding its contradictory counterpart in a quality of the other. Mind is a pure self-determined unity, which is as it knows itself and knows itself as it is, which has no discretion of parts or capacity of division or determination from without. Matter is essentially discrete or infinitely divided; it is a pure passivity; and all its determination comes to it from without. The world is therefore, as it were, "cut in two with a hatchet," divided into two unrelated existences, which are held together only by the will of God. Spinoza cuts the knot, and avoids the arbitrariness of this solution, by treating extension and thought as two attributes separated only in respect of our intelligence, but each expressing fully the absolute substance. And something like the same view has been revived in recent times, by writers like Lewes and Mr Spencer, who speak of feelings and motions as two opposite "aspects" of the same fact. When we ask, however, *for whom* these attributes or aspects are a unity, it becomes clear that the intelligence which is regarded as standing on one side of the dualism must also be taken as transcending it, and relating the two sides to each other. Moreover, the correspondence of the two attributes upon which Spinoza insists and their contrariety upon which Descartes insists, when taken together, give us the idea of a correlative opposition, *i.e.*, of an opposition of elements which yet are necessary to each other. If, therefore, they cannot be simply identified as Spinoza identifies them, yet they need no external bond such as Descartes introduces to combine them; for they cannot exist apart from each other. Their opposition is held within the limits of their unity, and is no absolute contradiction, but rather an opposition which exists only as it is transcended. In other words, it is an abstract opposition, *i.e.*, it is an opposition of elements which seem to be irreconcilable till it is observed that they are correlative, that each exists or has a meaning only as it relates itself to, or passes out of itself into, the other, and that each, held in its abstraction and separation from the other, loses all the meaning that it seemed to have. For, as in an organic body each member or organ lives only in tension against the others, yet only as continually relating itself to the others, so the utmost opposition of mind to matter, of the intelligence to the intelligible world, presupposes their unity, and is only the realization of it.

There is here, however, something more than an ordinary case of correlation, for in this unity of opposites mind appears twice, once as one of the opposites, and again as the unity which transcends the opposition. This ambiguity becomes most obvious in theories like that of Mr Spencer, who speaks of "two consciousnesses," which cannot be resolved into each other, but yet which strangely form inseparable parts of one and the same consciousness. What, however, is really involved in such a statement is that the external world, which in the first instance presents itself as absolutely opposed in nature to the subject whose object it is, is yet one with that subject, and that therefore the antagonism of mind to its object is only the last differentiation through which it realizes its unity with itself. In Hegel's language, that which presents itself as other than mind is *its* other—"an other which is not another," whose difference and opposition to itself it overreaches and overcomes. We must, therefore, regard the independence and externality of nature, its indifference, and even, as it seems, opposition, to the development of the moral and intellectual life of man, as merely apparent. For man, in this point of view, is not merely one natural being among others, but the being in whom nature is at once completed and transcended. If, therefore, at first he appears to stand in merely accidental and external relations to the other existences among which he finds himself, yet the whole process of his life—the process by which he comes to know the external world, and by which, reacting upon it, he makes it the means to the realization of an individual and social life of his own—is the negation of this contingency and externality. In all this process he is showing himself to be a being who can only know himself as he knows the objective world, and who can only realize himself as he makes himself the agent of a Divine purpose, to which all things are contributing.

Such an idea of man's relation to the world is necessarily involved in any theory that goes beyond that subjective idealism or sensationalism which denies to him every object of knowledge except his own states of feeling, and every end of action except his own pleasures and pains. Recent speculation, indeed, has suggested a compromise by which this dilemma is supposed to be evaded and mankind are represented as forming an organic unity in themselves, though they are still conceived as standing in an external and accidental relation to nature, the forces of which by their knowledge and skill they have subdued and are more and more subduing to their service. Such a compromise we find in the philosophy of Comte, the first writer who starting from an apparently empirical basis, was able to break through the individualistic prejudices of the school of Locke. In the latter volumes of his *Positive Philosophy* still more in his *Positive Politics*, Comte so far transcends individualism as to deny the externality of men to each other, and to declare that "the individual as such, is an abstraction, and that in reality he cannot be separated from the social organism, which is thus not merely an extraneous condition of his development, but essential to his very existence as man. Thus individual men exist only through the universal—through the spirit of the family, of the nation, of humanity, which manifests itself in them as a principle of life and development. Yet this organic unity, according to Comte, is in contact with a world which in relation to it is external and contingent. Nature has not its final cause in man, but on the contrary is, at first, rather his enemy, and it is to humanity itself that the praise is due if to a certain extent the enemy has been turned into a servant. The unity of life which manifests itself in humanity cannot therefore be considered as a universal principle, as the principle of the whole universe, but simply as the principle of the limited existence of man, which is hemmed in on every side by external and, in the main, unknown conditions. If humanity therefore is an organism, it is an organism existing in a medium which in reference to it is inorganic, *i e*, in a medium which has no essential relation to the life which animates man.

It is obvious, however, that this theory is an illogical attempt to find a standing ground between two opposite philosophies,—between the philosophy which treats man merely as a natural individual, placed among other individual beings and things, and which therefore regards his relation to them as something accidental and external, and the philosophy which treats him as a spiritual subject, a conscious and self conscious being, and regards him therefore as having no *merely* external relations either to other men or to nature. Comte shrinks from regarding the world without us as the manifestation of that spiritual principle which is also within us, which constitutes our very nature as individual men, and therefore connects us with the world at the same time that it separates us from it. Yet he recognizes the existence in us of a principle which is so far universal that it constitutes a community between all men. He thinks that the individual can transcend himself, so far as to see all things, not indeed from a Divine point of view, *sub specie æternitatis*, but from the point of view of universal humanity, and that in conformity with this theoretical consciousness, he can live a practical life of altruism, *i e.*, a life in which he identifies his own good with the good of humanity. But the philosophy that has gone so far must logically go further. It is impossible to treat humanity as an organism without extending the organic idea to the conditions under which the social life of humanity is developed. The medium by aid of which, or in reacting against which, the organized being maintains itself is an essential part of its life, it remains organic only in so far as it can mould itself to its conditions, and its conditions to itself. This is true even of the animal organism in relation to its small circle of conditions, which, however, is part of a larger circle to which the animal has no relation. But a conscious being is a *universal* centre of relations, there is nothing which it, as conscious, cannot make part of its own life. Hence the application of the organic idea to it involves its application to the whole world. And, if the recognition of a universal principle manifested in humanity naturally led Comte to the idea of the worship of humanity, the recognition of a universal principle manifested in man and nature alike must lead to the idea of the worship of God.

The rationality of religion, then, rests on the possibility of an ultimate synthesis in which man and nature are regarded as the manifestation of one spiritual principle. For religion involves a faith that, in our efforts to realize the good of humanity, we are not merely straining after an ideal beyond us, which may or may not be realized, but are animated by a principle which within us and without us is necessarily realizing itself, because it is the ultimate principle by which all things are, and are known. This absolute certitude that we work effectually because all the universe is working with us, or, in other words, because God is working in us, can find its explanation and defence only in a philosophy for which "the real is the rational, and the rational is the real. And such a philosophy, beginning with the Kantian doctrine that existence means existence for a spiritual or thinking subject, must go on to prove that that only can exist for such a subject which is the manifestation of thought or spirit, and, conversely, that spirit or intelligence is essentially self manifesting, or, in other words, that it cannot be conceived except as standing in essential relation to an external and material world. Finally, if nature be thus regarded as a necessary manifestation of spirit, it can be opposed to spirit only in so far as spirit in its realization becomes opposed to itself. In other words, nature must be regarded as, from a higher point of view, included in spirit. Nature exists that it may show itself to be spiritual in and to man, who transcends it yet implies it, who finds in it the necessary basis of his thought and action, but only that he may build upon it a higher spiritual life.

> Nature is made better by no mean
> But nature makes that mean so over the art
> Which, you say, adds to nature is an art
> Which nature makes

Only the order of precedence suggested by these words must be inverted. For, as nature only is for spirit, so the spiritual energy which reacts upon nature is that which manifests for the first time what nature in reality is. It is the consciousness of this—*i e*, of the identity of that which is realizing itself within and without us,—the consciousness that the necessity which is the precondition of our freedom is the manifestation of the same spirit which makes us free—which turns morality into religion. For it is this alone which enables us to regard the realization of the highest ends of human life as no mere happy accident, or as a conquest to be won by the cunning of man from an unfriendly or indifferent destiny, but as the result towards which all things are working.

In this philosophy, which finds its most adequate expression in the works of Hegel, there are two things which may be distinguished—the general idealistic view of the world, and the dialectical movement of thought in which Hegel develops and expresses it. And there are perhaps many at the present time who are prepared to accept the former, but who yet suspect, or even reject, the latter. And no doubt there is much in Hegel's *Logic* and *Philosophy of Spirit*, and still more in his *Philosophy of Nature*, which there is reason to regard with distrust. In clever hands that are not checked by a sufficient consciousness of the whole, the Hegelian dialectic may be made into the means of producing a seeming proof of anything. Nor is it always easy to determine how far Hegel himself was tempted by an impatient consciousness of the universality of his method to employ it in cases where the conditions of its successful application were wanting. Sometimes he seems to forget, what he himself teaches, that science must first have generalized experience and determined it by its finite categories ere it is possible for philosophy to give its final interpretation. Yet, when we realize the nature of that interpretation and of the transformation of science which philosophy by means of it proposes to effect, it becomes clear that the dialectic of Hegel is no extraneous addition to his idealism but is part and parcel of the same movement of thought. For this dialectic rests on the idea that thought or self-consciousness finds in its own organic unity the ultimate key to all difficulties in regard to the objects of thought and their relations to each other and to the mind. Self-consciousness, as has been already shown, is implicitly the whole web of categories which it throws over the world, and by aid of which it makes the world intelligible. All these it contains in itself; and, as it proceeds to determine the meaning of things, it simply produces its store, and exhausts itself on the object. Now, if it be idealism, in the strict sense of the word, to make thought or self-consciousness the principle and ultimate explanation of all that exists, it is obvious that we cannot separate idealism from such a dialectic as this, which is nothing more than the mind's consciousness of its own movement or process of self-affirmation. If to find thought in things be more than an empty word, then the movement or process which thought is must explain at once the transition from thought to what in opposition to it we call "things," and must give us the means of reconciling that opposition. In other words, the same movement by which thought determines itself as self-conscious, *i.e.* as a unity realized through difference, must also be conceived as the explanation of the difference between pure thought and the world, and as the solution of that difference in the idea of absolute spirit.

Such idealism has a close relation to Christianity; it may be even said to be but Christianity theorized. It has often been asserted that Hegel's philosophy of religion is but an artificial accommodation to Christian doctrine of a philosophy which has no inherent relation to Christianity. If, however, we regard the actual development of that philosophy it would be truer to say that it was the study of Christian ideas which first produced it. What delivered Hegel from the mysticism in which the later philosophies of Fichte and Schelling tended to lose themselves and led him, in his own language, to regard the absolute not merely as substance but as subject,—what made him recognize with Fichte that the absolute principle is spiritual and yet enabled him with Schelling to see in nature, as the opposite of spirit, the very means of its realization,—was his thorough appreciation of the ethical and religious meaning of Christianity. In the great Christian aphorism that "he who loseth his life alone can save it" he found a key to the difficulties of ethics, a reconciliation of hedonism and asceticism. For what this saying implies is that a spiritual or self-conscious being is one who is in contradiction with himself when he makes his individual self his end. In opposing his own interest to that of others, he is preventing their interests from becoming his; all things are his, and his only, who has died to himself. But if this be the truth of morality, it is something more, for "morality is the nature of things." We cannot separate the law of the life of man from the law of the world in which he lives. And, if it is the nature of things, as it is the nature of spirit, that he who loseth his life shall save it, the world must be referred to a spiritual principle, and the Christian doctrine of the nature of God is only the converse of the Christian law of ethics. To Hegel, starting from this point, a new light was thrown on the Fichtean treatment of the idea of self, and the Fichtean proof that the consciousness of self implies a relation to an object which is opposed to the self, and which yet from another point of view—since an object exists only for a subject—cannot be anything but an element of its own life. It was seen that this movement of thought is no mere fluctuation between contradictory positions, to be terminated finally by an *ipse dixit* of faith, but that the unity of the opposite elements is apprehensible by the intelligence, and that indeed it is *its* presence to the intelligence which makes the consciousness of opposition possible. It was in this sense that Hegel could say that that unity of opposites which had been called unintelligible by previous writers was just the very nature of the intelligence, and that only a view of the world guided by this idea could be properly intelligible, while every other view must contain in it an unsolved contradiction, an element that remains permanently impervious to thought.

The great objection to a metaphysic like this, at least an objection which weighs much in the minds of many, is that which springs from the contrast between the claim of absolute knowledge which it seems to involve and the actual limitations which our intelligence encounters in every direction. If the theory were true, it is felt we ought to be nearer the solution of the problems of our life, practical and speculative, than we are; the riddle of the painful earth ought to vex us less; we ought to find our way more easily through the entanglement of facts, and to be able to deal with practical difficulties in a less tentative manner. Yet there is really no antagonism between such a doctrine and a consciousness of the limitation of our faculties; nay rather, it is only on such a theory that a rational distrust of ourselves can be based. When Aristotle meets the warning that we should think finite and human things since we are finite and human with the answer that we ought rather, so far as in us lies, to rise to what is immortal and divine, he is not denying the limits of man's knowledge and power; on the contrary, he is rather pointing to the very principle which makes us conscious of those limits; for it is just because there is in man a principle of infinity that he knows his finitude, and, conversely, it is just in the consciousness of this finitude that he rises above it. A rational humility is possible only to one who has in himself the measure of his own weakness, and who, if he "trembles like a guilty thing surprised," is yet conscious that he is trembling before himself. This truth is often expressed by Kant with special relation to the moral consciousness, as where he contrasts the limitation of man, as a sensible being, occupying an infinitesimal space in the boundless world of sense, with his freedom from all limitation as a personal self, a member of the truly infinite world of intelligence. But it is not necessary to adopt Kant's abstract division of the sensible from the intelligible world to see that the consciousness of the greatness of the problem which has to be solved in human life and thought is deepened and widened by that very idea of philosophy which yet gives us the assurance that the problem is not insoluble, and even that, in principle, it is already solved.

(E. C.)

METAPONTUM, or METAPONTIUM (the first form is that generally found in Latin writers, but Thucydides, Strabo, and other Greek authors employ the latter form), was a city of Magna Græcia situated on the Gulf of Tarentum, near the mouth of the river Bradanus, and distant about 24 miles from Tarentum and 14 from Heraclea It was founded by an Achæan colony about 700 B C, though various traditions existed which assigned it an earlier origin But according to the only historical account it was a joint foundation from Sybaris and Crotona, to which, as usual in similar cases, was joined a body of fresh settlers from the mother country, under the command of a leader named Leucippus The object of its establishment was without doubt to strengthen the Achæan element in Magna Græcia, as opposed to the increasing power of the Tarentines, but at the same time to occupy a territory which was remarkable for its fertility It was to this cause that Metapontum owed the great prosperity to which it attained at an early period, and appears to have continued to enjoy for several centuries, though it never assumed a prominent place in history It was, however, one of the cities that played a conspicuous part in the political troubles arising from the introduction of the Pythagorean principles into the cities of Magna Græcia, and it was there that the philosopher himself ended his days His tomb was still shown there in the time of Cicero

At the time of the Athenian expedition to Sicily (415 B.C) Metapontum appears to have been an opulent and powerful city, whose alliance was courted by the Athenians but they contented themselves with a very trifling support In 332 B C, at the time of the expedition of Alexander, king of Epirus, into Italy, it was one of the first cities to espouse his cause, and enter into an alliance with him, and they appear to have in like manner lent an active support to Pyrrhus at a later period Down to this time, therefore, Metapontum seems to have retained its position as one of the principal cities of Magna Græcia, and there is no evidence of its having suffered materially from the establishment of the Lucanians in its immediate neighbourhood Nor have we any account of the precise period at which it passed under the dominion of Rome, or the conditions under which it became subject to the great republic But it was the Second Punic War which gave the fatal blow to its prosperity After the battle of Cannæ in 216 B C it was among the first cities in the south of Italy to declare in favour of Hannibal, and after the fall of Tarentum in 212 B C it not only received a Carthaginian garrison, but became for some years the headquarters of Hannibal Hence, when the defeat of Hasdrubal at the Metaurus (207 B C) compelled him to abandon this part of Italy, and withdraw into the fastnesses of Bruttium, the whole mass of the inhabitants of Metapontum abandoned their city, and followed him in his retreat

From this time Metapontum sunk into a poor and inconsiderable town, though it was still existing as such in the days of Cicero, it soon fell into complete decay, and Pausanias tells us that in his time nothing remained of it but a theatre and the circuit of the walls All remains of these have since disappeared, but the site is still marked by the ruins of a temple, which occupy a slight elevation on the right bank of the river Bradanus, about 2 miles from its mouth The surrounding plain, so celebrated in ancient times for its fertility, is now desolated by malaria, and almost uninhabited, and the remains of the city itself, between the site of the temple and the sea, are in great part buried in the alluvial deposits of the neighbouring rivers

Some excavations were carried on upon the spot by the Duc de Luynes in 1828, and the results of his researches were published by him in a special work (*Métaponte*, fol, Paris, 1833).

METASTASIO (1698–1782) Pietro Trapassi, the Italian poet who is better known by his assumed name of Metastasio, was born in Rome, January 6, 1698 His father, Felice Trapassi, a native of Assisi, came to Rome and took service in what was termed the Corsican regiment of the papal forces He subsequently married a Bolognese woman, called Francesca Galasti, and established himself in business as a sort of grocer in the Via dei Cappellari. Two sons and two daughters were the fruit of this marriage The eldest son Leopoldo, must be mentioned, since he played a part of some importance in the poet's life Pietro, while quite a child, showed an extraordinary talent for improvisation, and often held a crowd attentive in the streets while he recited impromptu verses on a given subject. It so happened that, while he was thus engaged one evening in the year 1709, two men of high distinction in Roman society passed by and stopped to listen to his declamation. These were Gian Vincenzo Gravina, famous for legal and literary erudition, famous no less for his dictatorship of the Arcadian Academy, and Lorenzini, a critic of some note Gravina was at once attracted by the boy's poetical talent and by his charm of person, for little Pietro was gifted with agreeable manners and considerable beauty The great man interested himself in the genius he had accidentally discovered, made Pietro his protegé, and in the course of a few weeks adopted him Felice Trapassi was glad enough to give his son the chance of a good education and introduction into the world under auspices so favourable. Gravina, following a fashion for which we may find precedents so illustrious as that of Melanchthon, Hellenized the boy s name Trapassi into Metastasio, and this name remained with him for life Gravina intended his adopted son to be a jurist like himself He therefore made the boy learn Latin and begin the study of law At the same time he cultivated his literary gifts, and displayed the youthful prodigy both at his own house and in the Roman coteries. Metastasio soon found himself competing with the most celebrated improvisatori of his time in Italy Days spent in severe studies, evenings devoted to the task of improvising eighty stanzas at a single session, were fast ruining Pietro s health and overstraining his poetic faculty At this juncture Gravina had to journey into Calabria on business He took Metastasio with him, exhibited him in the literary circles of Naples, and then placed him under the care of his kinsman Gregorio Caroprese at a little place called Scaléa In country air and the quiet of the southern sea shore Metastasio s health revived It was decreed by the excellent Gravina that he should never improvise a line again His great facility should be reserved for nobler efforts, when, having completed his education, he might enter into competition with poets who had bequeathed masterpieces to the world

Metastasio responded with the docility of a pliant nature to his patron's wishes At the age of twelve, while attending to classical and legal studies, he translated the *Iliad* into octave stanzas, and two years later he composed a tragedy in the manner of Seneca upon a subject chosen from Trissino's *Italia Liberata*—Gravina s favourite epic It was called *Giustino* Gravina had it printed in 1713, but the play is lifeless, and forty two years afterwards we find Metastasio writing to his publisher, Calsabigi, that he would willingly suppress it Caroprese died in 1714, leaving Gravina his heir, and in 1718 Gravina also died Metastasio inherited from the good old man a property, consisting of house, plate, furniture, and money, which amounted to 15,000 scudi, or about £4000 At a meeting of the Arcadian Academy, amid the tears and plaudits of that learned audience, he recited an elegy on the patron who had been to him so true a foster-father, and then settled down, not it seems without real sorrow for his loss, to enjoy what was no inconsiderable, fortune at that period Metastasio was now twenty During the last four years he had worn the costume of abbé, having taken the minor orders without which it was then useless to expect advancement in Rome His romantic history, personal beauty, charming manners and distinguished talents made him fashionable That before two years were out he had spent his money and increased his reputation for wit will surprise no one He now very sensibly determined to quit a mode of life for which he was not born, and to apply himself seriously to the work of his profession Accordingly he went to Naples, and entered the office of an eminent lawyer named Castagnola It would appear that he articled himself as clerk, for Castagnola, who was a stern master averse to literary trifling, exercised severe control over his time and energies While slaving at the law Metastasio did not wholly neglect the Muses In 1721 he composed an epithalamium, and probably also his first musical serenade, *Endimione*, on the occasion of the marriage of his patroness the Princess Pinelli di Sangro to the Marchese Belmonte Pignatelli But the event which fixed his destiny was the following In 1722 the birthday of the empress had to be celebrated with more than ordinary honours, and the viceroy applied to Metastasio to compose a serenata for the occasion He accepted this invitation with mingled delight and trepidation, for Castagnola looked with no favour on his clerk s poetical distractions It was arranged that his authorship should be kept a profound secret Under these conditions Metastasio produced *Gli Orti Esperidi* Set to music by Porpora, it won the most extraordinary applause The great Roman prima donna, Marianna Bulgarelli, called La Romanina from her birthplace who had played the part of Venus in this drama was so enraptured with the beauties of the libretto that she spared no pains until she had discovered its author Asked point blank whether he had not written the words of the successful play, Metastasio was obliged to answer Yes La Romanina forthwith took possession of him, induced him to quit his lawyer s office and promised to secure for him fame and independence if he would devote his talents to the musical drama It was thus that the opera already partially developed by the Cæsarean poet, Apostolo Zeno, attained perfection The right man had been found for maturing this form of art which the genius of the age demanded, but which was still but incomplete In La Romanina s house Metastasio became acquainted with the greatest composers of the day,—with Porpora, from whom he took lessons in music, with Hasse, Pergolese, Scarlatti, Vinci Leo, Durante, Marcello, all of whom were destined in the future to set his plays to melody Here too he studied the art of singing, and learned to appreciate the style of such men as Farinelli His singularly pliant genius discerned the conditions which the drama must obey in order to adapt itself to music in the stage it then had reached Gifted himself with extraordinary facility in composition, and with a true poetic feeling, he found no difficulty in producing plays which, while beautiful in themselves, judged merely as works of literary art, became masterpieces as soon as their words were set to music, and rendered by the singers of the greatest school of vocal art the world has ever seen Reading Metastasio in the study, it is impossible to do him justice Our only chance of rendering him a portion of his due is to approach these lyrical scenes—so passionate in their emotion, so cunningly devised for musical effect—with the phrases of Pergolese or Paesiello ringing in our ears, and to imagine how a Farinelli or a Caffariello voiced those stanzas which demand for their artistic realization the "linkèd sweetness long drawn out ' of melodies as the Italian school developed them In short, Metastasio is a poet whose poetry leaps to its real life in the environment of music The conventionality of all his plots, the absurdities of many of his situations, the violence he does to history in the persons of some leading characters, his "damnable iteration" of the theme of love in all its phases, are explained and justified by music He can still be studied with pleasure and profit But our only chance of understanding the cosmopolitan popularity he enjoyed is by remembering that at least one half of the effect he aimed at has been irrecoverably lost

Metastasio resided with La Romanina and her husband in Rome The generous woman, moved by an affection half maternal half romantic, and by a true artist s admiration for so rare a talent, adopted him more passionately even than Gravina had done She took the whole Trapassi family—father, mother, brother, sisters—into her own house She fostered the poet s genius and pampered his caprices. Under her influence he wrote in rapid succession the *Didone Abbandonata*, *Catone in Utica*, *Ezio*, *Alessandro nell Indie*, *Semiramide Riconosciuta*, *Siroe*, and *Artaserse*. These dramas were set to music by the chief composers of the day, and performed in the chief towns of Italy Every month added to Metastasio s renown But meanwhile La Romanina was growing older she had ceased to sing in public, and the poet felt himself more and more dependent in an irksome sense upon her kindness He gained 300 scudi (about £60) for each opera, this pay, though good, was precarious, and he longed for some fixed engagement. Abandoning himself gradually to despondent whims and fancies, it became clear that some change in his condition was desirable And the opportunity for a great change soon presented itself In September 1729 he received the offer of the post of court poet to the theatre at Vienna, with a stipend of 3000 florins This he at once accepted. La Romanina unselfishly sped him on his way to glory. She took the charge of his family in Rome, and he set off for Austria

In the early summer of 1730 Metastasio settled at Vienna in the house of a Spanish Neapolitan, Niccolò Martinez, where he resided until his death This date marks a new period in his artistic activity Between the years 1730 and 1740 his finest dramas, *Adriano*, *Demetrio*, *Issipile*, *Demofoonte*, *Olimpiade*, *Clemenza di Tito*, *Achille in Sciro*, *Temistocle*, and *Attilio Regolo*, were produced for the imperial theatre Some of them had to be composed for special occasions, with almost incredible rapidity—the *Achille* in eighteen days, the *Ipermnestra* in nine Poet, composer, musical copyist, and singer did their work together in frantic haste The impress of the peculiar circumstances under which they were created is still left upon them, not only in negligence of style, but also in an undefinable quality which marks them out as products of collaboration But what must always surprise us is that they should be as good as they are Metastasio understood the technique of his peculiar art in its minutest details The experience gained at Naples and Rome, quickened by the excitement of his new career at Vienna, enabled him almost instinctively, and as it were by inspiration, to hit the exact mark aimed at in the opera

At Vienna Metastasio met with no marked social success His plebeian birth excluded him from aristocratic circles But, to make up in some measure for this comparative failure, he enjoyed the intimacy of a great lady, the Countess Althann, sister in law of his old patroness the Princess Belmonte Pignatelli She had lost her husband, and had some while occupied the post of chief favourite to the emperor Metastasio's liaison with her became so close that it was even believed they had been privately married From his letters to his friend La Romanina, and to the great singer Farinelli, who reigned supreme at the court of Madrid, we learn the little details of the poet's life in its wearisome monotony, and come to comprehend his character, at once generous and timid, selfish and amiable, prudent almost to excess of caution, and personally cold in contradiction with the fervour of his sentimental muse. The even tenor of this dull existence was broken in the year 1734 by the one dark and tragic incident of his biography. It appears that La Romanina had at last got tired of his absence. Little satisfied with his friendly but somewhat reticent communications, impatient to see him once again, inquisitive perhaps about the terms on which he lived with his new mistress, she resolved to journey to Vienna. Could not Metastasio get her an engagement at the court theatre? The poet at this juncture revealed his own essential feebleness of character. To La Romanina he owed almost everything as a man and as an artist. But he was ashamed of her and tired of her. He vowed she should not come to Vienna, and wrote dissuading her from the projected visit. The tone of his letters alarmed and irritated her. It is probable that she set out from Rome, but died suddenly upon the road. Nothing can be said for certain about her end, or about the part which Metastasio may have played in hastening the catastrophe. All we know is that she left him her fortune after her husband's life interest in it had expired, and that Metastasio, overwhelmed with grief and remorse, immediately renounced the legacy. This disinterested act plunged the Bulgarelli-Metastasio household at Rome into confusion. La Romanina's widower married again. Leopoldo Trapassi, and his father and sister, were thrown upon their own resources. The poet in Vienna had to bear their angry expostulations upon his ill-timed generosity, and to augment the allowances he made them.

As time advanced the life which Metastasio led at Vienna, together with the climate, told upon his health and spirits. From about the year 1745 onward he writes complainingly of a mysterious nervous illness, which plunged him into the abyss of melancholy, interfered with his creative energy, and constantly distressed him with the apprehension of a general breakdown. He wrote but little now, though the cantatas which belong to this period, and the canzonet *Ecco quel fiero istante*, which he sent to his friend Farinelli, rank among the most popular of his productions. It was clear, as his latest and most genial biographer, Vernon Lee, has phrased it, that 'what ailed him was mental and moral ennui.' In 1755 the Countess Althann died, and Metastasio was more than ever reduced to the society which gathered round him in the bourgeois house of the Martinez. He sank rapidly into the habits of old age, and, though his life was prolonged till the year 1782, very little can be said about it. On the 12th of April he died, bequeathing his whole fortune of some 130,000 florins to the five children of his friend Martinez. He had survived all his Italian relatives.

During the long period of forty years in which Metastasio may be almost said to have overlived his originality and creative powers his fame went on increasing. In his library he counted as many as forty editions of his own works. They had been translated into French, English, German, Spanish, even into Modern Greek. They had been set to music over and over again by every composer of distinction, each opera receiving this honour in turn from several of the most illustrious men of Europe. They had been sung by the best virtuosi in every capital, from Madrid to St. Petersburg, from London to Constantinople. The critics of all nations vied in raising Metastasio's credit to the skies. There was not a literary academy of note which had not conferred on him the honour of membership. Strangers of distinction passing through Vienna made a point of paying their respects to the old poet at his lodgings in the Kohlmarkt Gasse. Letters of congratulation, adulation, sympathy, respect, condolence, poured in upon him. And yet, during the whole of this long period, he was gradually outliving the artistic conditions upon which that fame was really founded. It has been already pointed out that Metastasio cannot rank as a poet in the unqualified sense of that word, but as a poet collaborating with the musical composer and performer. His poetry, furthermore, was intended for a certain style of music—for the music of omnipotent vocalists, of thaumaturgical soprani. With the changes effected in the musical drama by Gluck and Mozart, with the development of orchestration and the rapid growth of the German manner, a new type of libretto came into request. Metastasio's plays fell into undeserved neglect, together with the music to which he had linked them. Farinelli, whom he styled "twin brother," was the true exponent of his poetry; and, with the abolition of the class of singers to which Farinelli belonged, Metastasio's music suffered eclipse. It was indeed a just symbolic instinct which made the poet dub this unique soprano his twin brother.

The musical drama for which Metastasio composed, and in working for which his genius found its proper sphere, has so wholly passed away that it is now difficult to assign his true place to the poet in Italian literary history. Compared with Shakespeare, or even with Racine, he hardly merits the title of a dramatist. His inspiration was essentially emotional and lyrical. Instead of creating characters he created situations for the display of very varied feelings, for all the feelings in fact to which melody allies itself. But in doing this he showed a capable playwright's faculty. His personages act and react upon each other. Their characters, though not in harmony with history or fact, are clearly traced and cleverly sustained. Each of the dramatis personæ is an emotion incarnate and consistent, admirably fitted for musical effect and contrast. The clash and combat of passions are vividly presented, with the smallest possible expenditure of rhetoric, in the dialogues intended for recitative. The climax of emotion is cadenced in appropriate stanzas, with simple but effective imagery, at the close of each important scene. The chief dramatic situations are expressed by lyrics for two or three voices, embodying the several contending passions of the agents brought into conflict by the circumstances of the plot. The total result is not pure literature, but literature supremely fitted for musical effect. Language in Metastasio's hands is exquisitely pure and limpid. Of the Italian poets, he professed a special admiration for Tasso and for Marini. But he avoided the conceits of the latter, and was no master over the refined richness of the former's diction. His own style reveals the improvisatore's facility. Of the Latin poets he studied Ovid with the greatest pleasure, and from this predilection some of his own literary qualities may be derived. The pedantic rules of Aristotelian poetics never touched an artist who felt his real vocation to be the interpretation of music. For historical propriety, for the psychology of character, for unity of plot, for probability of incident, he had a supreme disregard. It was indeed his merit to have discarded all these considerations. His poetry was the twin sister of Italian melody, and he was right in trusting entirely to music and action on the stage to render his conceptions vital. What the poet gained during his own lifetime, while the musical system to which he subordinated his genius was yet living, he has since lost, when, as now, he must be studied by readers who have only a faint and dim conception of that perished art. For sweetness of versification, for limpidity of diction, for delicacy of sentiment, for romantic situations exquisitely rendered in the simplest style, and for a certain delicate beauty of imagery, sometimes soaring to lyrical sublimity, he deserves to be appreciated so long as the Italian language lasts.

There are numerous editions of Metastasio's works. That by Calsabigi (Paris, 17[illegible], [illegible] vols. 8vo), published under his own superintendence, was the poet's favourite. Another of Turin (1[illegible]) and a third of Paris (1780) deserve mention. His posthumous works were printed at Vienna (1[illegible]). The collected editions of Genoa (1802) and Padua (1811) will probably [illegible]

[illegible] a work which throws a flood of light upon the development of Italian dramatic music and upon the place occupied by Metastasio in the artistic movement of the last century. [J. A. S.]

METCALFE, CHARLES THEOPHILUS METCALFE, BARON (1785–1846), a distinguished administrator, was born at Calcutta on January 30, 1785; he was the second son of Thomas Theophilus Metcalfe, then a major in the Bengal army, who afterwards became a director of the East India Company, and was created a baronet in 1802. Having been educated at Eton, where he read extensively, he in 1800 sailed for India as a writer in the service of the Company. After studying Oriental languages with success at Lord Wellesley's college of Fort William, he, at the age of sixteen, received an appointment as assistant to Lord Cowley, then resident at the court of Sindhia; in 1802 he became assistant in the office of the chief secretary; in 1803 he was transferred to that of the governor-general, and in 1806 to that of the commander-in-chief. On August 15, 1806, he became first assistant to the resident at Delhi, and in 1808 he was selected by Lord Minto for the difficult post of envoy to the court of Ranjít Sinh at Lahore; here, on April 25, 1809, he successfully concluded the important treaty securing the independence of the Sikh states between the Sutlej and the Jumna Four years afterwards he was made principal resident at Delhi, and in 1819 he received the appointments of secretary in the secret and political department, and of private secretary to the governor general (Lord Hastings) From 1820 to 1823 Sir Charles (who succeeded his brother in the baronetcy in 1822) was resident at the court of the nizam, but in the latter year he was compelled by the state of his health to retire from active service, in 1825 however, he was so far restored as to undertake the residency of the Delhi territories Two years afterwards he obtained a seat in the supreme council, and in February 1835, after he had for some time been governor of Agra, he, as senior member of council provisionally succeeded Lord William Bentinck in the governor generalship During his brief tenure of office (it lasted only till March 28, 1836) he originated or carried out several important measures, including that for the liberation of the press, which while almost universally popular, complicated his relation with the directors at home to such an extent that he withdrew from the service of the Company in 1838 In the following year he was appointed by the Melbourne administration to the governorship of Jamaica where the difficulties created by the recent passing of the Negro Emancipation Act had called for a high degree of tact and ability Sir Charles Metcalfe's success in this delicate position was very marked (see vol xiii p 551) but unfortunately his health compelled his resignation and return to England in 1842 Six months afterwards he was appointed by the Peel ministry to the governor generalship of Canada and his success in carrying out the policy of the home Government was rewarded with a peerage shortly after his return in 1845 He died at Malshanger, near Basingstoke September 5, 1846 See J W Kaye's *Life and Correspondence of Charles Lord Metcalfe* London, 1854

METELLUS the name of the most important family of the Roman plebeian gens Cæcilia They rose to distinction during the Second Punic War and Nævius satirized them

Quintus Cæcilius Metellus Macedonicus, prætor 148 B C in Macedonia, defeated Andriscus in two battles, and forced him to surrender He then superintended the conversion of Macedonia into a Roman province He tried unsuccessfully to mediate between the Achæan league and Sparta, but, when the Achæans advanced he defeated them easily near Scarphea Mummius soon after superseded him, and returning to Italy he triumphed in 146 Consul in 143, he reduced northern Spain to obedience In 131 censor with Q Pompeius (the first two plebeian censors), he proposed that all citizens should be compelled to marry He was a moderate reformer and was considered the model of a fortunate man before his death in 115 three of his sons had been consuls one censor, and the fourth was a candidate for the consulship

Quintus Cæcilius Metellus Numidicus whose reputation for integrity was such that when he was accused of extortion the jury refused to examine his accounts was selected to command against Jugurtha in 109 B C He subjected the army to rigid discipline and aimed solely at seizing Jugurtha himself he defeated the king by the river Muthul, and next year after a difficult march through the desert, took his stronghold Thala Marius however, accused Metellus of protracting the war and received the consulate for 107 Metellus returned to Rome and triumphed Saturninus whom as censor he tried to remove from the senate passed in 100 an agrarian law, inserting a provision that all senators should swear to it within five days All complied but Metellus, who retired to Asia After Saturninus was killed, he returned, but died shortly after under suspicion of poison

Quintus Cæcilius Metellus Pius, so called from his efforts to restore his father Numidicus, commanded in the Social War, defeating Q Pompædius (88 B C) Sulla on departing gave him proconsular command over South Italy When Marius returned, the soldiers, who had no confidence in Octavius, wished Metellus to command, but he refused Metellus retired to Africa and afterwards to Liguria, resuming his former command on Sulla's return In 86 he gained a decisive victory over Norbanus at Faventia In Sulla's proscriptions he pleaded in favour of moderation Consul in 80 with Sulla, he went to Spain next year against Sertorius, who pressed him hard till the arrival of Pompeius in 76 Next year Metellus defeated Sertorius's lieutenant Hirtuleius at Italica and Segovia, and joining Pompeius rescued him from the consequences of a check at Sucro From this time Sertorius grew weaker till his murder in 72 Metellus had previously set a price on his head In 71 he returned to Rome and triumphed He was an upright man, of moderate ability

Quintus Cæcilius Metellus Pius Scipio, son of Scipio Nasica, was adopted by the preceding He was accused of bribery in 60 B C, and defended by Cicero In August 52 Pompeius procured him the consulate Scipio in return supported Pompeius, now his son in law On war being resolved on, Scipio was sent to Syria His extortions were excessive, and he was about to plunder the temple of Artemis at Ephesus when he was recalled by Pompeius He commanded the centre at Pharsalus, and afterwards went to Africa, where by Cato's influence he received the command In 46 he was defeated at Thapsus in his flight to Spain he was stopped by a corsair and stabbed himelf His connexion with two great families gave him importance but he was selfish and licentious, and his violence drove many from his party

Quintus Cæcilius Metellus Celer, prætor 63 B C, was sent to cut off Catiline's retreat northward Consul in 61, his personal influence prevented the holding of the Compitalia which the senate had forbidden and the tribunes permitted He opposed the agrarian law of the tribune L Flavius, and stood firm even though imprisoned the law had to be given up He also tried, though fruitlessly, to obstruct Cæsar's agrarian law in 59 He died that year under suspicion of poison given by his wife Clodia

METEMPSYCHOSIS, the transmigration of the soul, as an immortal essence, into successive bodily forms, either human or animal This doctrine, famous in antiquity, and one of the characteristic doctrines of Pythagoras, appears to have originated in Egypt This indeed is affirmed by Herodotus (ii 123) —"The Egyptians are, moreover, the first who propounded the theory that the human soul is immortal and that when the body of any one perishes it enters into some other creature that may be born ready to receive it, and that, when it has gone the round of all created forms on land, in water, and in air, then it once more enters a human body born for it, and this cycle of existence for the soul takes place in three thousand years"

Plato, in a well known passage of the *Phædrus*, adapts, as was his wont, the Pythagorean doctrine to his myth or allegory about the soul of the philosopher That soul, he says, though it may have suffered a fall in its attempt to contemplate celestial things, still is not condemned, in its first entrance into another form, to any bestial existence, but, according to its attainments, *i e*, to the progress which it has made in its aspiration for celestial verities, it passes, in nine distinct grades, into the body of some one destined to become a philosopher, a poet, a king, a general, a seer, &c or, if very inferior, it will animate a sophist or an autocrat (τυραννος) Plato extends the cycle of existence to ten thousand years, which is subdivided into periods of a thousand years, after the lapse of which the souls undergo judgment, and are admitted to everlasting happiness or condemned to punishment[1] It is after the period of a thousand years, he adds, that the human soul comes into a beast, and from a beast again into a man, if the soul originally was human

Pythagoras, who was said to have travelled in Egypt,[2] brought this fantastic doctrine into Magna Græcia, and made it a prominent part of his teaching He declared that he had himself been Euphorbus, the son of Panthus, in the time of the Trojan War, and had successively inhabited other human bodies, the actions of all which he remembered[3] Closely connected with his theory of metempsychosis was his strict precept to abstain from animal food, even from eggs from some kinds of fish, and (for some unknown, probably symbolical, reason) from beans[4] There can be no doubt that the Egyptian custom of preserving the mummies of cats, crocodiles, and some other creatures had its origin in the notion that they had been inhabited by souls which might some day claim these bodies for their own We cannot suppose that Plato or the later Greeks really believed in the transmigration of souls, though there are many allusions to it generally of a somewhat playful character Thus Menander in the play called *The Inspired Woman*[5] (Θεοφορουμενη) supposes some god to say to an old man, Crato 'When you die you will have a second existence choose what creature you would like to be dog, sheep, goat horse or man ' To which he replies 'Make me anything rather than a man, for he is the only creature that prospers by injustice

Absurd and fantastic as such a doctrine as metempsychosis appears at first sight to be, it was in reality a logical deduction from primitive ideas about the nature of the soul It is necessary to explain these ideas (which have important bearings on other questions) in order to show that metempsychosis was almost a necessary corollary to the belief that the soul was the vital or animating principle,—that the one distinction between organic and inorganic was the existence in the former of a *ψυχη*

The difference between a dead body and a living body —or rather, one principal difference—was that the living animal breathed and it was observed that, as soon as the breath left the body, not only did warmth and motion cease, but the body began to decay Life, therefore, was breath, an opinion tacitly expressed by the Greek and Roman vocabulary, *animus*, *anima* (ἄνεμος) ψυχη πνεῦμα, *spiritus* But breath is air, and air is eternal and imperishable in its very nature Therefore the "soul, or portion of air which gave animation to the body, did not perish at the dissolution of the body, but it was returned to the element of which it was composed, and out of which it came It followed that, from the countless millions of 'souls" emancipated from bodies in all time, and still flitting about invisibly in space, the air must literally swarm with souls,—a doctrine taught by Pythagoras[6] Hence, any creature, human or bestial, that first drew the breath of life, might, so to say, swallow a soul, *i e*, take in with the act of respiration the very same particles of air which had animated some former body For, although the soul was air, and returned to its kindred element, it was supposed to retain a peculiar character in intelligence (φρόνησις), remembrance of the past, and knowledge an experience gained in some former existence Any creatur which first breathed might or might not inhale this or tha soul, just as a net thrown into the water may catch this o that fish, or no fish at all But if no "soul ' was inhale the creature was believed for that reason to die, and th different degrees of intelligence observed in different me and animals led to the notion that there must have bee a difference in the souls that first animated them Eve the belief that the soul, especially near the time of dissolution from the body, could foretell future events was base on the notion of intelligence and consciousness resultin from experiences of the past[7]

As all the science of modern times cannot say precisel what life is, nor how it first came upon this earth, it is no wonderful that so obvious, though wholly erroneous, a explanation should have presented itself to primitive ma when first he began to inquire into the causes of things The extension of life, by the same term *ψυχη*, to plants an apparently non breathing things, which, however, had birth growth, and death, was a development of a philosophic age and we are not surprised to find Aristotle recognizing on form of life as *vegetable*, *φυτικον*[8] The irrational confusio of "soul with sentient bodily functions, the attribution t spirits (εἴδωλα) of motion, speech, or other muscular an material action, though still common, while metempsychosi is derided or forgotten, is in reality, perhaps, a less excusable superstition

The Romans inherited the doctrine of metempsychosi from Ennius, the poet of Calabria, who must have bee familiar with the Greek teachings which had descended t his times from the cities of Magna Græcia In his *Annals* or Roman history in verse, Ennius told how he had see Homer in a dream who had assured him that the sam soul which had animated both the poets had once belonge to a peacock, a story that might seem to indicate India traditions The *Pavo Pythagoreus* and the *Somnia Pythagorea* are referred to by Persius and Horace as well as b Lucretius[9]

Theories suggesting element worship naturally led to th notion that air and ether (upper air) were divine[10] Henc every soul, as being but a portion of it, was in itself divine and therefore immortal We thus see that the doctrine o the immortality of the soul, whether attained by a soun or a vicious course of reasoning, was an inevitable conclusion for early thinkers Pantheism taught that all th universe was pervaded by a divine mind, and Virgil cite the opinion of some, that the intelligence of bees was du to a portion of this universal mind residing in them, a vie closely allied to the doctrine of metempsychosis[11] A divin thing might be polluted but not destroyed hence th notion of purifying souls by airing them or burning awa a material defilement is enlarged upon by Virgil in th sixth book of the *Æneid* (724 *sq*) (F A P)

METEOR, METEORITE The term meteor, in ac cordance with its etymology (μετεωρος), meant originall something high in the air It has been applied to a larg variety of phenomena most of them of brief duratio which have place in the atmosphere Disturbances in th air are aerial meteors, viz winds, tornadoes, whirlwind typhoons, hurricanes, &c The vapour of water in th atmosphere creates by its forms and precipitations th aqueous meteors, viz, clouds, fogs, mists, snow, rain, hail

---

[1] P 249 A Comp Rev xx 2 13, Virg, *Æn* vi 745 "Donec longa dies perfecto temporis orbe concretam exemit labem,' &c

[2] Diogen Laert, viii 1 3 Lucian, *Gallus* § 18 *sq* where the doctrine of metempsychosis and the stories about the pre existence of Pythagoras are wittily satirized

[3] Lucian *Gallus*, §§ 4, 5, Diodor Sic x §§ 9 10 Hor *Od* i 28, 10 'habentque Tartara Panthoiden iterum Orco demissum

[4] *Gallus*, 19, 33 For fanciful reasons for the prohibition of beans, see Lucian, *Vitarum Auctio*, § 5

[5] Frag 222, Meineke

[6] Diogen. Laert., viii. 1, § 32, *εἶναι πάντα τὸν αερα ψυχῶν*

[7] Diodor Sic xviii § 1

[8] *Ethics* lib i 13

[9] Pers *Sat* vi 9 Hor, *Epist* ii 1 52 Lucret, i 124

[10] ὦ δῖος αἰθὴρ Prometheus exclaims Æsch *Prom*, 88

[11] *Georg* iv 219—

His quidam signis atque hæc exempla secuti
Esse apibus partem divinæ mentis et haustus
Ætherios dixere, deum namque ire per omnes

&c The effect of light upon the atmosphere and its contents causes certain luminous meteors, viz, rainbows, halos, parhelia, twilight, mirage, &c Discussion of all these, and of like phenomena, belongs to **Meteorology** (*q v*)

Another class of luminous meteors, known as shooting or falling stars, fireballs, bolides, &c, have their place in the upper parts of the atmosphere But by reason of their origin from without they, and the aerolites or meteorites which sometimes come from them, belong properly to astronomy The term meteor is often used in a restricted sense as meaning one of these latter phenomena The present article will treat of them alone

The most remarkable of the meteors (and the most instructive) are those which are followed by the falling of stones to the earth These have since the beginning of the present century attracted so much attention, and the phenomena have been so frequently examined and described by scientific men, that they are very well understood The circumstances accompanying the fall of stones are tolerably uniform A ball of fire crosses the sky so bright as to be visible, if it appears in the daytime sometimes even at hundreds of miles from the meteor and if it appears in the night it is bright enough to light up the whole landscape It traverses the sky generally finishing its course in a few seconds It suddenly goes out either with or without an apparent bursting in pieces and after a short period a loud detonation is heard in all the region near the place where the meteor has disappeared Sometimes only a single stone, sometimes several are found For some falls they are numbered by thousands About three thousand were obtained from the fall of L Aigle in 1803, scattered over a region about 7 miles long and of less breadth A like number was obtained from the fall of Knyahinya on June 9, 1866 At Pultusk a still larger number were collected scattered over a larger space by a fall in January 1868 From the Emmet county (Iowa) fall May 10, 1879, a similarly large number have been secured

These meteors leave behind them in the air a cloud or train that may disappear in a few seconds, or may remain an hour They come at all times of day, at all seasons of the year, and in all regions of the earth They come irrespective of the phases of the weather, except as clouds conceal them from view

Let us describe one or two of these meteors more in detail On the evening of the 2d of December 1876 persons in or near the State of Kansas saw, about eight o clock in the evening a bright fireball rising from near where the moon then was in the western sky It increased in brilliancy as it proceeded, becoming so bright as to compel the attention of every one who was out of doors To persons in the northern part of the State the meteor crossed the southern sky going to the east to those in the southern part it crossed the northern heavens To all it went down near to the horizon a little to the north of east the whole flight as they saw it occupying not over a minute

The same meteor was seen to pass in nearly the same way across the heavens from west south west to east north east by inhabitants of the States of Nebraska, Iowa Missouri Wisconsin Illinois Michigan, Kentucky Indiana, Ohio, Pennsylvania, and West Virginia But besides this there were heard near the meteor s path four or five minutes after its passage loud explosions like distant cannonading, or thunder, or like the rattling of empty waggons over stony roads So loud were these that people and animals were frightened East of the Mississippi river these explosions were heard everywhere within about 60 miles of the meteor's path, and in Bloomington Indiana, sounds were heard supposed to come from the meteor even at a distance of nearly 150 miles from it Over central Illinois it was seen to break into fragments like a rocket, and over Indiana and Ohio it formed a flock or cluster of meteors computed to be 40 miles long and 5 miles broad The sky in New York State was wholly overcast Persons in Ohio and Pennsylvania, who from their situation could look over the cloud last, saw the meteor passing on eastward over New York From many places in the State itself came accounts of rattling of houses, thundering noises, and other like phenomena, which at the time were attributed to an earthquake

At one place in northern Indiana a farmer heard a heavy thud as of an object striking the ground near his house The next morning he found on the snow a stone of very peculiar appearance weighing three quarters of a pound, which from its character there is every reason to believe came from the meteor By putting together the various accounts of observers, the meteor is shown to have become first visible when it was near the north west corner of the Indian Territory, at an elevation of between 60 and 100 miles above the earth From here it went nearly parallel to the earth s surface, and nearly in a right line, to a point over central New York During the latter part of its course its height was 30 or 40 miles It thus traversed the upper regions of the air through 25° of longitude and 5° of latitude in a period of time not easily determined, but probably about two minutes A part of the body may have passed on out of the atmosphere, but probably the remnants came somewhere to the ground in New York, or farther east

A somewhat similar meteor was seen in the evening of July 20 1860, by persons in New York, Pennsylvania, New England, &c, which first appeared over Michigan, at a height of about 90 miles The light was so brilliant as to call thousands from their houses It passed east-south east and over New York State at a height of about 50 miles, broke into three parts which chased each other across the sky At New York city it was seen in the north, while at New Haven it was in the south At both places the apparent altitude was well observed and its true height proved to be about 42 miles above the earth s surface between the two cities It finally disappeared far out over the Atlantic Ocean It is doubtful whether any one heard any sound of explosion that came from this meteor, and no part of it is known to have reached the ground The velocity was at least 10 or 12 miles per second, or fifty times the velocity of sound These two meteors were evidently of the same nature as those which have furnished so many stones for our museums, except that the one was so friable that it has given us but one known fragment, while the other was only seen to break in two, not even a sound of explosion being known to have come from the meteor

Next to the stone producing meteor is the fireball, or bolide, which gives generally a less brilliant light than the former, but in essential appearances is like it The meteor of July 20, 1860, above described, though unusually brilliant, was one of this class, and represents thousands of bolides which have been seen to break in pieces The bolides leave trains of light behind them just as the stone meteors do, they travel with similar velocities both apparent and actual, and in all respects exhibit only such differences of phenomena as would be fully explained by differences in size, cohesion, and chemical constitution of stones causing them

Next to the bolide is a smaller meteor which appears as if one of the stars were to leave its place in the heavens, shoot across the sky, and disappear—all within the fraction of a second Some meteors of this class are as bright as Venus or Jupiter Some are so small that though you look directly at the meteor, you doubt whether you see one or not In the telescope still smaller ones are seen that are invisible to the naked eye Meteors comparable in brightness to the planets and the fixed stars are usually called shooting stars

These various kinds of meteors differ from all other luminous phenomena so as to stand in a group entirely alone Though they have been sometimes regarded as separable among themselves into three or four different species, and for purposes of description may still be so divided, yet they all seem to have a like astronomical character, and the differences are only those of bigness, chemical constitution velocity &c There appears to be no clear line of distinction between the stone producing and the detonating meteors nor between those heard to explode and those seen to break in pieces nor between these and the simple fireballs, nor between the fireball and the faintest shooting star

Altitudes of Meteors—The first important fact about the meteors is the region in which they become visible to us In hundreds of instances observations have been made upon the luminous path of a meteor at two or more stations many miles apart When such stations and the path are properly situated relatively to each other observations carefully made will show a parallax by which the height of the meteor above the earth the length and direction of the path and other like quantities may be computed The general result from several hundred instances is that the region of meteor paths may be in general regarded as between 40 and 80 miles above the earth's surface Some first appear above 80 miles and some descend below 40 miles But an altitude greater than 100 miles, or one below 25 except in the case of a stone furnishing meteor must be regarded as very doubtful Thus the meteor paths are far above the usual meteorological phenomena which (except auroras and twilight) have not one tenth of the height of the meteors But with reference to all other astronomical phenomena they are very close to us The comets for example are well nigh a millionfold, and even the moon is a thousandfold more distant from us

Velocities of Meteors—When the length of a luminous path is known and the time of describing it has been observed it is easy to compute the velocity in miles Unfortunately the large meteors, describing long path come at rare intervals and unexpectedly and it is a happy accident when one is observed by a person accustomed to estimate correctly short intervals of time On the other hand the total time of visibility of the shooting stars which come so frequently that they may be watched for is usually less than a second It is not easy to estimate correctly such an interval where the beginning and ending are not marked by something like a sharp click Hence all estimates and computations of velocities of meteors are to be received with due regard to their uncertainty We may only say in general that the velocities computed from good observations are rarely if ever under 8 or 10 miles a second, or over 40 or 50 miles and that some have far greater velocities than others The average velocity seems to be nearly 30 miles

What makes the Luminous Meteor The cause of a meteor is now universally admitted to be something that enters the earth's atmosphere from without with a velocity relative to the earth that is comparable with the earth's velocity in its orbit, which is 19 miles per second By the resistance it meets in penetrating the air the light and other phenomena of the luminous train are produced Under favourable circumstances, portions of these bodies reach the earth's surface as meteorites

Meteoroids—A body which is travelling in space, and which on coming into the air would under favourable circumstances become a meteor, may be called a meteoroid

The meteoroids are all solid bodies It would hardly be possible for a small quantity of gas out in space to retain such a density as would enable it on coming into the air to go 10 or 100 miles through even the rare upper atmosphere, and give us the clear line which a shooting star describes Even if a liquid or gaseous mass can travel as such in space, it would be instantly scattered on striking the air, and would appear very unlike a shooting star or bolide

Numbers of Meteors—Of the larger meteors there are in the mean six or eight per annum which in the last fifty years have furnished stones for our collections A much larger number have doubtless sent down stones which have never been found Thus Daubrée estimates for the whole earth an annual number of six or seven hundred stone falls

But of the small meteors or shooting stars the number is very much larger Any person who should in a clear moonless night watch carefully a portion of the heavens would in the mean see at least as many as eight or ten shooting stars per hour A clear sighted and practised observer will detect somewhat more than this number Dr Schmidt of Athens from observations made during seventeen years obtained fourteen as the mean hourly number on a clear moonless night for one observer during the hour from midnight to 1 A M A large group of observers, as has been shown by trial would see at least six times as many as a single person By a proper consideration of the distribution of meteor paths over the sky and in actual altitude in miles so as to allow for mists near the horizon, it appears that the number over the whole globe is a little more than ten thousand times as many as can be seen in one place This implies that there come into the air not less than twenty millions of bodies daily each of which, under very favourable conditions of absence of sunlight, moonlight clouds and mists, would furnish a shooting star visible to the naked eye Shooting stars invisible to the naked eye are often seen in the telescope The numbers of meteors if these are included would be increased at least twentyfold

How densely Space is filled with Meteoroids—By assuming that the absolute velocity of the meteors in space is equal to that of comets moving in parabolic orbits (we have good reason to believe that this is nearly their true velocity) we may prove from the above numbers that the average number of meteoroids in the space that the earth traverses is in each volume equal to that of the earth about thirty thousand In other words there is in the average to every portion of space equal to a cube whose edge is about 210 miles one meteoroid large enough to make a shooting star bright enough to be visible to the naked eye Such meteoroids would upon an equable distribution be each in round numbers 200 miles from its nearest neighbour All these numbers rest upon Dr Schmidt's hourly number fourteen and for a less practised observer and a less clear sky they would be correspondingly changed How much they would need to be altered to represent other parts of space than those near the earth's orbit is a subject of inference rather than of observation

Motion in Space—The meteoroids whatever be their size, must by the law of gravitation have motions about the sun in the same way as the planets and comets that is in conic sections of which the sun is always at one focus The apparent motions of the meteors across the sky imply that these motions of the meteoroids relative to the sun cannot as a rule be in or near the plane of the ecliptic For if they were there, since the motion of the earth is also in the ecliptic, the motion of the meteoroids relative to the earth would be in the same plane This would involve that all the meteor paths as seen on the sky would if produced backward cross the ecliptic above the horizon In fact there is no tendency of this kind Hence the meteoroids do not move in orbits that are near the ecliptic as the planets do, but like the comets they may and usually do have orbits of considerable inclinations

Numbers through the Night —There are more meteors seen in the morning hours than in the evening If the meteors had no motion of their own in space, the earth would by its motion receive the meteors only on the hemisphere that was in front There would be no meteors seen in the other hemisphere On the other hand if the meteors had such large velocities of their own as that the earth's velocity might be neglected in comparison, and if the directions of the meteors motions were towards all points indiscriminately, then as many would be seen in one part of the night as another In fact there are about three times as many seen in the morning hours as in the evening The law of change from evening to morning gives a means of proving that the mean velocity of meteors is so great that they must in general be moving in long orbits about the sun In this respect also the meteoroids resemble comets and are unlike planets, in their motions Of the stone furnishing meteors more are seen in the day than in the night, and more in the earlier hours of the night than in the later This is probably due to the fact that more persons are in a position to see the stone falls at the periods of greater abundance

Star Showers —While the average number of shooting stars for a single observer at midnight may be regarded as tolerably constant, there have been special epochs when many more have been seen In certain instances the sky has been filled with the luminous trains, just as it is filled by descending snowflakes in a snowstorm, making a veritable shower of fire One of the best-observed, though by no means the most brilliant, of these showers occurred on the evening of the 27th of November 1872 Some of the observers of that shower, counting singly, saw at the rate of eight or ten thousand shooting stars in the course of two hours The distances of the meteoroids in the middle of the swarm which the earth then passed through, each from its nearer neighbours, would be 30 or 40 miles

The following quotations show the impression made by star showers in times past —

> "In the year 286 [of the Hegira] there happened in Egypt an earthquake on Wednesday the 7th of Dhu l Ka dah lasting from the middle of the night until morning and so called flaming stars struck one against another violently while being borne eastward and westward northward and southward and no one could bear to look toward the heavens on account of this phenomenon
>
> ' In the year 599 [of the Hegira] on the night of Saturday on the last day of Muharram stars shot hither and thither in the heavens eastward and westward and flew against one another like a scattering swarm of locusts to the right and left people were thrown into consternation, and cried to God the Most High with confused clamour
>
> 'These meteors [November 12 1799] might be compared to the blazing sheaves shot out from a firework
>
> "The phenomenon was grand and awful the whole heavens appeared as if illuminated with sky rockets
>
> November 13 183 Thick with streams of rolling fire scarcely a space in the firmament that was not filled at every instant
>
> "Almost infinite number of meteors they fell like flakes of snow

November Meteors or Leonids —These quotations all refer (except possibly the first) to a shower which has appeared in October and November of many different years since its first known occurrence on the 13th of October 902 A D Dates of these showers are given in the following table —

Oct 13 902	Oct 17 1101	Oct 28 1602	Nov 13 1833
Oct 15 931	Oct 19 1202	Nov 9 1698	Nov 14 1866
Oct 14, 934	Oct. 23 1366	Nov 12, 1799	Nov 14 1867
Oct 15, 1002	Oct 25 1533	Nov 13, 1832	Nov 14 1868

On several years after 1833, and before and after 1866-68, there were unusual numbers of those meteors seen on the mornings of November 13, 14, and 15, though perhaps they would have been unnoticed had there not been special watching for them It will be seen that all these showers are at intervals of a third of a century, that they are at a fixed day of the year, and that the day has moved steadily and uniformly along the calendar at the rate of about a month in a thousand years The change of twelve days in the 17th century is due to the change from old to new style

The only explanation of this periodical display that is now seriously urged, and the one which is universally accepted by astronomers, is that there is a long thin stream of meteoroids, each of which is travelling about the sun in a conic section These conic sections are all nearly parallel, and have nearly the same major axis, extending out about as far as to the orbit of Uranus, and each requiring the common period of thirty three and a quarter years The length of the stream is such that the most advanced members are six or eight years ahead of the hindermost, and they all cross the earth's orbit with a velocity of about 26 miles a second Since the earth plunges through the group nearly in the opposite direction, the velocity with which they enter the air is 44 miles a second One of the facts which have greatly aided us in arriving at this explanation is that these meteors in all the years and through all hours of the night cross the sky as we look at them in lines which diverge from a point near the centre of the sickle in the constellation Leo, hence the paths in the air are parallel This implies that their velocities relative to the sun are all parallel and equal to each other The radiation from Leo has given to them the name *Leonids*

Orbit of the Leonids —This orbit, common to all the Leonid meteors, is inclined to the ecliptic at an angle of 17° (or rather 163°, since the motion is retrograde), has a major axis of 10 34, a periodic time of 33 27 years, and a perihelion distance a little less than unity

The above orbit, and that alone, explains the several appearances of the November meteors, the annual and the thirty three year periods, the radiation from Leo, and the change of day of the month in the course of the centuries This it does so completely that the result has never been questioned by astronomers Shortly after the publication by Professor Adams in 1867 of the last link in the chain of the proof of this orbit, there was also published the definitive orbit of the comet 1866 I That the comet was running almost exactly in the orbit of the meteors was at once recognized In fact the comet is itself, in a sense, a meteoroid, and the principal member, so far as we know, of the group Leonids had been seen in 1863, two years and two months in advance of the comet, while those of 1866 were ten months behind it Those of later years (a few Leonids were seen even in 1870) were extended along the line of the comet's path behind it The leaders of this long file of meteoroids had passed up beyond the orbit of Jupiter long before those which brought up the rear had crossed that planet's orbit going down toward the sun. The thickness of the stream is less than the ten thousandth part of its length In the densest part that we have recently passed through—namely, that traversed in 1833—the density of the stream may be expressed by saying that each meteoroid must in the mean have been 10 or 20 miles from its nearest neighbours

What makes this Comet and these Meteors describe the same Orbit about the Sun?—Its path might have been inclined to the ecliptic at any angle instead of 163°. Or, with this inclination, its plane might have cut the earth's orbit at any other place than where the earth is on the 14th of November Or, happening to have these two elements in common, it might have passed the earth's orbit nearer the sun or farther away from it than the earth is Or, having these three things in common, it might, by a slight difference in velocity, have had a periodic time much more or much less than thirty three years Or, with all these in common, it might have crossed the earth s orbit at a far different angle than the meteors These several independent elements for the comet and the meteors are substantially identical, and this identity proves almost beyond doubt that between the two either there is now an actual or else there has been in the past a causal connexion That there is now any physical connexion is thoroughly disproved by the immense magnitude of the stream, and by the isolation and distances from each other of the individual components It seems difficult to find any cause that should bring into such a strangely shaped group bodies that had originally orbits distributed at random Hence we are apparently forced to conclude that these meteoroids have something common in their past history In fact they seem to have been once parts of a single body, and these common elements are essentially those of the parent mass By some process not yet entirely explained they have become separated from the comet, thrown out of the control of its attractive power, and so left to travel each one in its own orbit If the cause of separation was not too violent, each new orbit would necessarily be but slightly different from that of the comet Very small variations in velocity, and hence in periodic time, would in the course of ages scatter the several individuals along the orbit even to the length of many hundreds of millions of miles

The Meteor Group is not the Comet s Tail—These meteoroids must be carefully distinguished from the comet s tails The former follow or precede the comet exactly in the comet s path, the particles that compose the latter are driven off by the sun s repulsion directly away from the comet s path The meteoroids and the comet have orbits with nearly common elements, the orbits of the particles of the tail have elements that are unlike each other and unlike those of the comet The meteoroids are undoubtedly solid masses the tails are pulverulent or gaseous

Twin Comets of 1366—The comet 1866 I is probably not the only one that has been connected with the November meteors In 1366 a few days after the earth went through the meteor stream a comet appeared in the northern heavens, and, passing directly in the line of the stream so close to the earth as to describe an arc of 90° in a single day, disappeared in the constellation Aquarius Immediately upon its disappearance a second comet was seen in the north, which followed nearly in the same path The Chinese accounts are not sufficiently exact to furnish independent orbits for them, but both comets were undoubtedly members of the Leonid stream The comet 1866 I may be identical with one of them

The Andromeds and Biela s Comet—Mention has been made of the star shower of November 27 1872 The periodical comet known as Biela s, which makes three revolutions in twenty years passes very near the earth s orbit at a longitude corresponding to November 27, but by reason of its direct motion the node has had considerable motion in longitude as the result of perturbations Meteors having the same orbits as Biela s comet would have a radiant in the constellation Andromeda that is would cross the sky in lines diverging from a point in that constellation They might, however, be at dates after or even before November 27

Unusual numbers of meteors were seen December 7, 1798 by Brandes A like abundance was seen December 7 1838 and, as they had been expected, and radiation was now looked for they were found to diverge from a point in Andromeda Hence they have been called Andromeds Since 1852 Biela s comet itself has been entirely lost The star shower of November 27, 1872, previously referred to, had a radiant in Andromeda, and in every way appeared as though its meteors had once been parts of Biela's comet A sprinkle three days earlier, on the night of November 24, had the same radiant, and came from a less dense outlying parallel stream A small comet was seen in the southern sky by Pogson in the direction opposite to the radiant shortly after the shower Biela s comet had been found in 1845 46 to be in two parts, which at its next return to perihelion in 1852 had separated to eight times their former distance But the meteor streams of 1872 could hardly have been separated from the comet so recently, and the Pogson comet if of the same origin must also have left the parent mass at an earlier date than 1845 No ordinary perturbations would in a short period have so changed the orbits The parts of the small stream traversed by the earth December 1838 and December 1798 were far from the comet, and these fragments must have been thrown off much earlier

The Perseids and the Comet 1862 III—There is a third epoch when meteors appear in unusual numbers viz, the 9th to 11th of August This sprinkle, as it may be called has been seen constantly at the time named for nearly fifty years and there are on record accounts of similar appearances in the earlier years before its annual character had been discovered Some observers have thought that there were evidences of a variation having a long period but the proof seems as yet unsatisfactory and the display may be regarded as tolerably constant from year to year On every 10th of August we may confidently expect a display of meteors that shall be at least four or five times as numerous as those of ordinary nights The radiant is in the constellation Perseus, and hence the name Perseids

The comet 1862 III which has a period of more than a hundred years passes close to the earth s orbit nearly cutting it at the place of this shower and has a velocity and direction corresponding to this radiant Hence a connexion of the Perseid meteors with this comet is presumed like that which the Leonids and Andromeds have with the comet 1866 I and Biela The meteors are distributed along this orbit more regularly than along either of the other two and at the same time the breadth of this group is a hundred times greater than that of the Leonids We must for the present regard it rather as a meteor ring the meteoroids being scattered along the entire conic section which the comet describes This ring has an inclination of 113° with the ecliptic

Meteors of April 20 21—*Lyraids*—About the 20th of April there have been several quite brilliant star showers, the earliest on record having been in the year 687 B C On that day meteors have been observed which radiated from Lyra and to these the name Lyraids has been given The comet 1861 I passes near the earth's orbit in that longitude and any meteors having such a connexion with it as is proved for the Leonids with comet 1866 I would also radiate from Lyra

Again, at several other periods of the year meteors have been seen in unusual numbers which seem to be connected with certain comets

Meteor Radiants—We have thus definite proof that the earth at certain epochs plunges through meteor streams, and that these streams travel along the same track as certain comets The question is at once asked—Do not the sporadic meteors, those which are seen on any and all nights of the year, belong to similar streams? An immense amount of labour has been spent in observing the paths of meteors, and classifying them, so as to detect and prove the existence of radiant points As many as a thousand such radiants have been suggested by the different investigators Some of these are duplicates, some will prove to be accidental coincidences but a goodly number may reasonably be expected to endure the test of future observations Such will show the existence of meteor streams, and perhaps will be connected with comets that are now known, or that may hereafter be discovered

The radiants have been spoken of as if they were points in the heavens This is so nearly true as to justify all the conclusions that have been deduced above But in fact a radiant, even in the star showers in which it is most sharply defined, must be regarded as a small area. The apparent meteor paths when produced backward do not exactly meet in a point If they be treated as proceeding from a small area, it does not appear that this is a long narrow one Hence it may be shown that the paths of the meteors in the air are not exactly parallel either to a line or to a plane This can hardly be due to a want of parallelism of the paths before the meteoroids meet the earth, but is rather due to their glancing as they strike the air These facts add not a little to the difficulties to be overcome by the energetic observers and investigators who are trying to deduce order out of an apparent chaos

Meteorites —The fragments which fall immediately after the disappearance of large meteors have been carefully collected and preserved in mineralogical museums, and have been studied with special interest The largest collections in Europe are in Vienna, Paris, London, and Berlin, some of these representing over three hundred localities In the United States there are large collections at New Haven, Amherst, and Louisville

In several respects these fragments differ at first sight from terrestrial rocks

They are when found almost always covered in part or entirely with a very thin black crust, generally less than $\frac{1}{50}$ of an inch in thickness This crust may have a bright lustrous surface, or it may be of a lustreless black It has evidently been melted, yet so rapidly as not to change in the least the parts of the stone immediately adjacent Streaks showing the flow of the melted matter are often seen on the surface Upon some surfaces are what appear to be deposits of the melted matter that has flowed off from the others Some surfaces are only browned, showing an apparently recent fracture, and some cracks are found in stones which are not yet completely broken in two

The surfaces very often have small cup like cavities, sometimes several inches in diameter, sometimes like deep imprints in a plastic mass made by the ends of the fingers and sometimes still smaller These "cupules have not only various sizes in different stones, but even in the same stone differ considerably from one surface to another They appear in meteorites that are almost exclusively iron, as well as in those mainly destitute of that metal, and they may be regarded as a characteristic of meteorites

The meteorites have usually metallic iron as one of their component parts Native iron is very rare indeed among terrestrial minerals, and its presence in the meteorites is therefore characteristic Sometimes the iron forms the principal part of the body, giving it the appearance of a mass of that metal Sometimes it forms only a connected framework which is filled in with mineral matter Sometimes particles of iron are scattered through a stony mass and a few meteorites are said to be destitute of metallic iron altogether The metallic iron is always accompanied with nickel

The stony meteors when broken or cut through have usually a greyish interior, and often exhibit a peculiar globular structure From the small rounded grains that give it this appearance the name chondrite (from χονδρος a ball) has been applied to this kind of meteorite Sometimes the irregular fragments are compacted into a kind of breccia

The pieces as we find them are always apparent fragments of some larger mass, and there is no structural appearance which would indicate that the mass might not be a fragment of a still larger one In some of the falls fragments picked up at a distance of miles from each other fit together in their simply browned surfaces showing that they were true fragments recently separated In some cases surfaces of the stones are partially polished In some a cross section of the stone exhibits thin black lines as though the melted matter of the surface had been forced into the crevices of the partially broken stone

The stones when seen to fall if at once picked up are usually too warm to be taken in the hand But cases are on record in which the stones were excessively cold They sometimes, on striking the ground, penetrate into it from 1 to 3 feet In extreme cases large ones have struck much deeper into soft earth Sometimes they are broken to pieces by the impact with the hard earth

The stones are usually not very large. Although the light of the meteor is such as sometimes to be seen over a region 1000 miles in diameter, and the detonation gives phenomena suggestive of an earthquake over many counties, yet a stone exceeding 100 ℔ is quite exceptional in our collections The total weight secured at any fall has rarely if ever amounted to a thousand pounds The average weight of nine hundred and fifty perfect specimens of the Pultusk fall in the Paris museum is 67 grammes, or less than 2½ oz One of the Hessle meteorites in the Stockholm museum weighs less than 1 grain Many of the Emmet county meteorites (May 10, 1879) are not much larger, though the largest specimen of that fall weighs nearly 500 ℔

Meteors traversing the Atmosphere —We can now get a very good idea of the history of that part of a meteorite's life between its entrance into the air and its arrival at the earth It is entirely invisible until it has reached that height at which the density of the air is enough to create considerable resistance Up to that time it moves almost exclusively in obedience to the sun's attraction The earth's attraction may be neglected, especially during the passage through the air Since the velocity is a hundred times that of sound, the elasticity of the air is impotent to remove it from in front of the meteorite, or to prevent a high degree of condensation Perhaps the air is liquefied immediately in front of the stone Heat is developed in it enormously, and the stone being pressed closely against the hot air is melted, with an intense light The condensed air charged with the melted matter is pushed aside, and left behind nearly in the wake of the meteor to form the train The brightness of the train rapidly diminishes behind the meteor, so that the light of the meteor and the train, modified by irradiation, make the whole appear to a distant eye of the shape of a pear or candle flame The stone being a poor conductor of heat and itself rigid, is not heated in the interior either by condensation or conduction, and may reach the ground with its surface only heated, while the interior is as cold as it had been out in space

If the stone is a small one it will soon be used up by this intense fire Until its front surface is rounded by the flame, the irregular resistances may cause such a stone to glance But if the stone is larger it will lose velocity less rapidly As it comes down into the region where the air is more dense, it will in spite of loss of velocity meet greater resistance The air pressed hard against it burns it unequally, forming cupules over its surface The pressure of the air cracks the stone,—perhaps scaling off small fragments, perhaps breaking it into pieces of more uniform size In the latter case the condensed air in front of the meteor being suddenly relieved will expand, giving the terrific explosion which accompanies such breaking up In either case a fragment may have still velocity enough to burn on for an instant in its new path and then come invisibly to the earth, covered with a coating, the greater part obtained after the principal explosion In the latter part of the course the original velocity has almost all disappeared, so that the sound travels faster than the meteor The air's resistance exceeds the earth's attraction, and the stones strike the ground only with the force of a spent cannon ball It is no doubt in violent disruption that some of the fractures are made in such a way as to give the rubbed and polished surfaces

Trains of Meteors —The smaller meteors generally have no perceptible train Only in exceptional cases do the trains of ordinary shooting stars remain visible longer than a fraction of a second An unusual number of the Leonids have a bluish train But the brighter shooting stars and the larger meteors sometimes have trains that endure for minutes, and in extreme cases for an hour Such trains are at first long narrow lines of light, though much shorter than the track of the meteor They begin at once to broaden in the middle and to fade away at one or both ends Presently they become curved, sometimes with two or three convolutions The white cloud floats slowly away among the stars, coiling up more and more, and finally fades out of sight The cause of all this seems to be as follows The heated air charged with the debris of the meteor is by the meteor's impact driven off horizontally, causing the narrow train to spread into a cloud The currents of air differing in direction at different altitudes twist the cloud into its varied fantastic forms Attempts to obtain the spectrum of the trains have been made, and sodium and magnesium lines have been thought to be detected in them The observation, however, is one that is not easy to make or confirm The trains have often colours other than white, and in the case of the brighter meteors different colours are seen in the different parts of the train

Magnitude—Some computations have been made of the size of the shooting star meteoroids from the mechanical equivalent of the light developed by their disintegration If all the energy of the meteor is changed into light, then these computations would be conclusive But a part is spent in disintegrating and burning the stone, a part in heating the air, and a part in giving direct motion to portions of air A computation based on the light developed gives only a lower limit to the size

It seems probable that the larger meteors might be safely regarded as weighing on entering the air only a few hundreds or at most a few thousands of pounds The smallest visible shooting stars may be equal in size to coarse grains of sand, and still be large enough to furnish all the light exhibited by them The largest shooting stars furnish matter enough to fill with thin trains cubic miles of space, but this need not require a very large mass

Meteoric Irons—There have been found at various times on the surface of the earth masses of metallic iron combined with nickel These have been so like the irons which have been known to fall, both in their structure and in composition, that they have been without hesitation classed among the meteoric irons A mass of this character weighing 1635 lb found in Texas is in the Yale College Museum The Charcas (Mexico) iron in the Paris museum is about the same size A ring shaped mass somewhat smaller, from Tucson, is in the United States National Museum in Washington A still larger mass is in the British Museum and many other large masses are in public collections or private

Widmannstatten Figures—If in any of the meteoric irons whether seen to fall or found on the earth, a section is cut and polished and then etched with acids a series of peculiar lines are developed which are known as Widmannstatten figures The lines of iron unattacked by the acid consist of an irregular grouping of parallel rulings often lying along the faces of a regular octahedron The exhibition of these figures and the combination of iron with nickel have been usually considered conclusive evidence of the meteoric origin of any iron mass

Nickel Iron of Ovifak—In 1870 Baron Nordenskiold in his voyage to Greenland, found on the shore of the island of Disco fifteen iron masses the largest of which weighed 20 tons all in an area of half an acre In the basaltic rocks not far distant other iron masses were found embedded in the basalt The presence of nickel with the iron, and the development of lines like the Widmannstatten figures, were at once accepted as proof of their meteoric origin, in spite of the combination with basalt A more complete examination has, however, established the terrestrial origin of these irons and given reasons to hope for new discoveries of relations existing between the earth and the meteors The additional discovery of small particles of metallic iron in certain other igneous rocks proves that the union of the Ovifak irons with basalt is not exceptional

Chemical Constitution of the Meteorites—No new element has been found in the meteorites Three elements most widely distributed and most important among the meteorites—iron, silicon, and oxygen—are also most abundant in our earth Daubree gives the following lists of elements, arranged somewhat in the degree of their importance, in meteorites (Maskelyne adds lithium and antimony).—

Iron
Magnesium
Silicon
Oxygen
Nickel
Cobalt
Chromium
Manganese
Titanium
Tin
Copper
Aluminium
Potassium
Sodium
Calcium
Arsenic
Phosphorus
Nitrogen
Sulphur
Chlorine
Carbon
Hydrogen

Minerals in Meteorites—Among the minerals in the meteorites there are several which occur in the rocks on the earth Among these are cited by Daubree peridote, pyroxene, enstatite, triclinic felspar, chromite, magnetic pyrites, iron oxide, graphite, and probably water Several minerals, however are found which, so far as now known, are peculiar to the meteorites —metallic nickel iron, phosphide of iron and nickel (schreibersite), sesquisulphide of chromium and iron (daubreelite), sulphide of calcium (oldhamite), and chloride of iron (lawrencite)

Meteorites of different falls are in general unlike, but there are many instances in which the stones of two falls are so similarly constituted that it is not easy to distinguish them

In four falls (Alais, Cold Bokkeveld, Kaba, and Orgueil) the stones contain little or no iron In these carbon appears not as graphite but in union with hydrogen and oxygen, and also with soluble and even deliquescent saline matters The combinations are such as to suggest the existence of humus and organic remains But after careful search nothing of this kind has been detected in them In general the meteorites show no resemblance in their mechanical or mineralogical structure to the granitic and surface rocks on the earth One condition was certainly necessary in their formation, viz, the absence of free oxygen and of enough water to oxidize the iron and other elements Perhaps it is to this fact that are due the resemblances between these minerals and those of the deep seated rocks of the earth in the formation of which free oxygen and water were also not present

Gases in Meteorites—The meteoric stones and irons when reduced to fine particles and placed in the vacuum of a Sprengel air-pump give off small quantities of gases which may be reasonably presumed to have been occluded by the irons at some time in their earlier history Professor Graham found hydrogen in meteoric irons Professor Wright has shown that a moderate heat drives off from the stony meteorites carbonic acid and carbonic oxide with a small amount of hydrogen As the heat increases the proportion of hydrogen (and even some nitrogen) increases till at a full red heat the hydrogen given off is by far the largest portion From the irons similar gases are given off, but the carbon compounds are not so large a component as hydrogen The spectra seen in the tails of comets are not strikingly like those of any of these gases But it is impossible to reproduce in the laboratory the conditions under which the matter of comets tails is giving off its light We cannot therefore say that these gases may not be the important parts of the cometic coma and tails

Meteoroid as Part of a Comet—Assuming that the meteorite and meteoroid once formed an integral part of a comet, not a little information is given us of the nature of this mysterious body. There is room also for speculation

First, the comet may be a single hard body which comes from the cold of space into the heat of the sun, and there has fragments broken off, just as a stone is shattered in a hot fire The nucleus of some of the comets must be very small because invisible in the telescope, and an impulse that would raise a stone on the earth only a few inches would send it permanently away from such a comet The exposure of new surfaces to the heat of the sun might give occasion for the development of gas to form the comet's tail

Or, secondly the comet may be a tolerably compact aggregation of small bodies not in contact each one being of the size of a meteoroid, and kept near to the rest, not by cohesion but by their combined attraction The total mass being small some members of the group near the comet's perihelion passage can be by the sun's perturbing action thrown out into orbits quite independent of the comet itself, and yet such as relative to the sun shall resemble that of the main group Perturbations resembling tidal waves might be preparing other members to be cast off at the next perihelion passage of the comet

In either case, if we suppose, as seems probable that the comet came from outside the solar system and that a disturbance by a large planet changed the original hyperbolic orbit into an ellipse, the comet must have passed that planet as a very compact group, if not in a single mass else the disturbance that changed the orbit would have scattered the group beyond the power of a future recognition of the common origin of the fragments

Meteoroids as Fuel of the Sun—The idea has been held by distinguished physicists that the meteoroids in falling into the sun furnish by their concussion a supply for the heat which the sun is constantly sending off into space,—that they are in fact the fuel of the sun Such a view, however, receives but little support from facts which we know about meteors The meteoroids of the August and two November periods are evidently permanent, members of the solar system moving in closed orbits The same is by inference highly probable for most of the other meteoroids, and may be true of all of them Permanent members of the solar system, however, if they ever fall into the sun, do so only after a long period of perturbation If any meteoroids come from stellar spaces and have any uniform or random distribution of velocities or directions, only a very small portion of these would hit the sun s surface The far greater portion would go on in hyperbolic orbits But the earth receives the impact of its portion of these foreign meteoroids, both in their inward and outward course and in addition encounters a full share of the permanent members of the solar system of which the sun receives very few or none It is not hard to show that a supply of meteoroids to the sun sufficient to make good its daily loss of heat would require that the twenty million meteoroids which the earth daily encounters even if all were from stellar space should have an average weight of hundreds of tons The facts do not warrant the admission of any such magnitude even for the large meteors much less for the ordinary and small shooting stars Whatever be the source of the sun s heat, all the meteoroids of which we know anything are totally inadequate to supply the waste

The literature of meteors and meteoroids is very much scattered It is mainly contained in the scientific journals and in transactions of learned societies The series of valuable *Reports* of the Luminous Meteor Committee of the British Association contains not only the record of an immense amount of original observations, but also year by year a digest of most of the important memoirs

Meteoric science is a structure built stone by stone by many builders In this article no attempt has been made to assign to each builder the credit for his contribution (H A N)

METEORA, a remarkable group of rock built monasteries in Thessaly, in the northern side of the valley of the Peneus, not quite 20 miles north east of Triccala, and in the immediate vicinity of the village of Kalabaka, Stagus, or Stagoi (the ancient Ægininm) From the Cambunian chain two vast masses of rock are thrust southward into the plain, surmounted by a number of huge isolated columns from 85 to 300 feet high, "some like gigantic tusks, some like sugar-loaves, and some like vast stalagmites," but all consisting of iron-grey or reddish-brown conglomerate of gneiss, mica-slate, syenite, and greenstone On the summit of these rocky pinnacles—accessible only by aid of rope and basket let down from the top, or in some cases by a series of almost perpendicular ladders climbing the cliff to the mouth of a tunnel—stand the monasteries of Meteora (τὰ Μετέωρα) At one time they were twenty four in number, but Holland (1812) and Hughes (1814) found them reduced to ten, at Curzon's visit (1834) there were only seven, and in 1853 not more than four of these were inhabited by more than two or three monks Meteora *par excellence* is the largest and perhaps the most ancient The present building was erected, according to Leake's reading of the local inscription, in 1388 (Bjornståhl, the Swedish traveller, had given 1371), and the church is one of the largest and handsomest in Greece St Barlaam s and St Stephen s (the latter founded by the emperor John Cantacuzene) are next in importance The decorations of the churches contain a large amount of material for the history of Byzantine art, not much inferior in value to the similar treasures at Athos

Unless the identification with the Ithome of Homer be a sound one there is no direct mention of the rocks of Meteora in ancient literature, and Professor Kriegk suggests that this may simply be due to the fact that they had not then taken on their present remarkable form Æginium however is described by Livy as a strong place, and is frequently mentioned during the Roman wars, and Stagus appears from time to time in Byzantine writers

See Holland *Travels in the Ionian Isles &c* 1815 Hughes *Travels in Greece and Albania* 1830 Curzon *Visit to Monasteries in the Levant* 1849 Leake *Northern Greece* Professor Kriegk in *Zeitschr f allg Erdk* Berlin 1858 Tozer, *Researches in the Highlands of Turkey* 1869

METEOROLOGY

METEOROLOGY, in its original and etymological sense, included within its scope all appearances of the sky, astronomical as well as atmospherical, but the term is now restricted to the description and explanation of the phenomena of the atmosphere which may be conveniently grouped under weather and climate These phenomena relate to the action of the forces on which the variations of pressure, temperature, humidity, and electricity of the atmosphere depend, but in an especial sense to the aerial movements which necessarily result from these variations

In the more exact development of meteorology, the scientific investigation of climate long preceded that of weather Humboldt s work on *Isothermal Lines*, published in 1817, must be regarded as the first great contribution to meteorological science The importance of this inquiry into the distribution of terrestrial temperature it is scarcely possible to overestimate, for, though the isothermals were necessarily to a considerable extent hypothetical, there cannot be a doubt that they presented a first sketch of the principal climates of the globe Dove continued and extended the investigation, and in his great work *On the Distribution of Heat on the Surface of the Globe*, published in 1852, gave charts showing the mean temperature of the world for each month and for the year together with charts of abnormal temperature To this, more than to any other work, belongs the merit of having popularized the science of meteorology in the best sense, by enlisting in its service troops of observers in all parts of the civilized world

In 1868 another series of important charts were published representing by isobaric lines the distribution of the mass of the earth's atmosphere, and by arrows the prevailing winds over the globe for the months and the year By these charts the movements of the atmosphere and the immediate causes of these movements were for the first time approximately stated, and some knowledge was thereby attained of some of the more difficult problems of meteorology It was shown that the prevailing winds are the simple result of the relative distribution of the mass of the earth s atmosphere, in other words, of the relative distribution of its pressure, the direction and force of the prevailing winds being simply the flow of the air from a region of higher towards a region of lower pressure, or from where there is a surplus to where there is a deficiency of air It is on this broad and vital principle that meteorology rests, which is found to be of universal application throughout the science, in explanation, not only of prevailing winds, but of all winds, and of weather and weather changes generally One of the more important uses of the principle is in its furnishing the key to the climates of the different regions of the earth, for climate is practically determined by the temperature and moisture of the air, and these in their turn are dependent on the prevailing winds, which are charged with the temperature and moisture of the regions they have traversed The isobaric charts show further that the distribution of the mass of the earth s atmosphere depends on the geographical distribution of land and water in their relations to the sun's heat and to radiation towards the regions of space in different seasons

In 1882 Loomis published a map showing the mean rainfall of the globe This map and others that have been constructed for separate countries show conclusively that the rainfall of any region is determined by the prevailing winds considered in relation to regions from which they have come, and the physical configuration and temperature of the part of the earth's surface over which they blow, The maximum rainfall is precipitated by winds which, having traversed a large breadth of ocean, come up against and blow over a mountainous ridge lying across their path, and the amount deposited is still further increased if the winds pass at the same time through regions the temperature of which constantly becomes colder On the other hand, the rainfall is unusually small, or *nil*, when the prevailing winds have not previously traversed some extent of ocean, but have crossed a mountain ridge and advance at the same time into lower latitudes, or regions the temperature of which is markedly higher

While the observational data for the determination of the geographical distribution of the prime elements of climate, viz, the pressure, temperature, moisture, and movements of the atmosphere and the rainfall were being slowly but surely collected, the great importance of the study of weather came gradually to be recognized Additional impetus was given to this branch of study from its intimate bearings on the eminently practical question of storm warnings Synchronous weather maps, showing the weather over a considerable portion of the earth s surface, were constructed, and some advance was made in tracing the progress of storms from day to day Unquestionably one of the first problems of meteorology is to ascertain the course storms usually follow and the causes by which that course is determined, so as to deduce from the meteorological phenomena observed, not only the certain approach of a storm, but also the particular course that storm will take The method of practically conducting this large inquiry in the most effective manner was devised by the genius of Leverrier, and begun to be carried out in 1858 by the daily publication of the *Bulletin International*, to which a weather map was added in September 1863 This map showed graphically for the morning of the day of publication the atmospheric pressure, and the direction and force of the wind, together with tables of temperature, rainfall, cloud, and sea disturbance from a large number of places in all parts of Europe From such weather maps forecasts of storms are framed and suitable warnings issued, but above all a body of information in a very handy form is being collected, the careful study and discussion of which is slowly but gradually leading to the issue of more exact and satisfactory forecasts of weather, and to a juster knowledge of these great atmospheric movements which form the groundwork of the science

The most cursory glance is sufficient to show that the ever changing physical phenomena with which it is the business of meteorology to deal are all referable to the action of the sun, it being evident that if the sun were blotted out from the sky a cold lifeless uniformity would rapidly take possession of the whole surface of the globe Meteorological phenomena naturally group themselves into two great classes,—those dependent on the revolution of the earth on its axis, and those dependent on its revolution round the sun taken in connexion with the inclination of its axis to the plane of its orbit The science thus divides itself into two great divisions, the first comprising diurnal phenomena and the second annual phenomena

DIURNAL MARCH OF PHENOMENA

Temperature—Of the daily changes which take place in the atmosphere, the first place must be assigned to those which relate to temperature, seeing that on these all other changes are either directly or indirectly dependent Observations of the temperature of the air are therefore of the first importance in meteorology A perfectly accurate observation of the temperature of the air is unquestionably among the most difficult to make of all physical observations, the difficulty being to eliminate the effects of radiation of surrounding objects The nearest approach yet made to the solution of this important problem of physical inquiry was made by Dr Joule in a communication to the Philosophical Society of Manchester (November 26, 1867, *Proc*, vol. vii p 35) But the manipulative skill and time demanded by the method there detailed render it quite unsuitable for general adoption anywhere in collecting the observational data required in the determination of this important element of climate It is therefore necessary to fall on some method which, while it gives results that can only be regarded as approximate secures the essential element of uniformity among the observations

Fig 1 represents Stevenson s louvre boarded box for the thermometers which is now very widely used for temperature observations The box is made of wood and louvred all round so as to protect the thermometers inside from radiation and at the same time secure as free a circulation of air as is consistent with a satisfactory protection from radiation The box is painted white both inside and outside and screwed to four stout wooden posts also painted white firmly fixed in the ground The posts are of such a length that when the thermometers are hung in position the bulbs of the minimum thermometer and hygrometer are exactly at the same height of 4 feet above the ground, the maximum thermometer being hung immediately above the minimum thermometer This thermometer box is placed over a plot of grass and in a free open space to which the sun s rays have free access during as much of the day as surrounding conditions admit of It will be observed that the thermometers are suspended on cross laths in the centre of the box and face the door which should always open to the north It is not possible to overestimate the importance of seeing that uniformity of height above ground and method of protecting the thermometers is secured, since in no other way is it possible to obtain results from different places which shall be comparable with each other and thus supply satisfactory materials for the investigation and development of comparative climatology

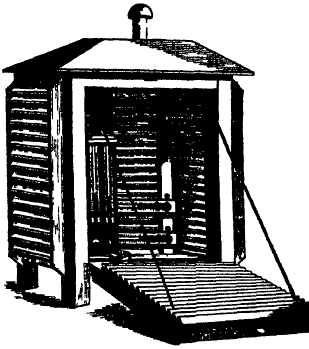


FIG 1 —Thermometer Box

A desired uniformity is yet far from being attained among the meteorological systems of different countries Thus in Russia the box for the protection of the thermometers is made of zinc, on the supposition that such a box follows more closely the changes of temperature of the air than a box of wood Owing to these international diversities of observation, it is extremely desirable that steps were taken to ascertain, by Joule s method of observing, the approximate errors peculiar to each sort of thermometer box, in order that the temperatures of different countries may be compared together in a more satisfactory manner than has yet been possible

Interchanges of temperature among bodies take place by conduction, convection, and radiation In meteorology the most important illustrations of conduction are the propagation downwards through the earth s strata of the changes of the temperature of the surface as it is heated during the day and cooled during the night and the propagation of the same changes of temperature through the lowest stratum of the air which rests on the surface Since sand and light loose soils are much worse conductors of heat than clay and dense soils, it follows that loose soils and tracts of sand are subject during the day to higher temperature and during the night to lower temperature near the surface than dense soils, and that frosts and extreme temperatures do not penetrate so far into loose as into dense soils. It is on these differences that some of the more striking features of climates depend. As snow is one of the worst conductors of heat, owing to the quantity of air filling the interstices among the ice crystals, it protects the soil it covers by setting a limit to the depth to which the severe frosts of the surface penetrate, and by arresting the escape of the heat of the soil upwards to the air.

The communication of heat from one part of the earth to another by convection is seen on a grand scale in the winds and in the currents of the ocean. It is seen also in the ascending and descending currents of the atmosphere everywhere, which have their origin in the daily and unequal changes of temperature to which the surface of the earth is subject. The direct and beneficial effect which results from atmospheric and oceanic circulation is a more equable distribution of temperature over the globe, thus moderating the rigours of the polar regions and the heat of the tropics.

An interchange of heat is constantly going on among bodies exposed to each other, whatever be their temperature. This mode by which heat is communicated from one body to another is called radiation. Radiant heat proceeds in straight lines, diverging in all directions from the source, is only in a limited degree influenced by the air through which it passes, and is not diverted from the straight course by the wind. The intensity is proportional to the temperature of the source, and is greater according to the degree of inclination of the surface on which the rays fall.

If then a body be placed in the presence of other bodies, some colder and some warmer than itself, it will from this mutual interchange of temperature receive more heat from the warmer bodies than it radiates to them, and consequently becomes warmer; but it will receive less heat from the colder bodies than it radiates to them and its temperature consequently falls. This is precisely the condition in which the earth is placed in space. When a part of the surface is turned towards the sun that part of the surface receives more heat than is radiated from it and the temperature consequently rises most in that region which for the time is perpendicular to the sun's rays and least round the annulus where the inclination of the surface is greatest. On the other hand since the hemisphere turned from the sun radiates more heat than it receives from the cold regions of space, the temperature there falls. Owing to the essentially distinct conditions under which the earth is placed with respect to radiation the subject falls naturally to be divided into two heads solar radiation and terrestrial radiation.

Solar Radiation.—Of the sun's rays which arrive at the earth's surface, those which fall on the land and solid bodies generally are wholly absorbed by the thin surface layer exposed to the heating rays, the temperature of which consequently rises. Whilst the temperature of the surface increases, a wave of heat is propagated downwards through the soil. The intensity of the daily wave of temperature rapidly lessens with the depth at a rate depending on the conductivity of the soil, until at about 4 feet below the surface it ceases to be measurable. Part of the heat of the surface layer is conveyed upwards through the air by the convection currents which have their origin in the heating of the lowermost stratum of air in direct contact with the heated surface of the land.

Altogether different is the influence of the sun's rays on water. In this case the sun's heat is not all, indeed very far from all, arrested at the surface, but penetrates to a considerable depth. The depth to which the influence of the sun is felt has been shown by the observations made during the cruise of the "Challenger" to be, roughly speaking, about 500 feet below the surface of the sea. The rate at which, in perfectly clear water, this heat is distributed at different depths is a problem that has not yet been worked out. Since water is a bad conductor, the heat thus distributed does not, as takes place with respect to land, penetrate to still lower depths by conduction, but only by different densities prevailing at the same depths, whether these different densities be due to different temperatures or different degrees of salinity. Thus one of the more important distinctions between land and water surfaces in their bearings on climate is that nearly all the sun's heat falling on land is arrested on the surface, whereas on water it is at once diffused downwards to a great depth. In examining temperatures of the sea taken at different depths, it is surprising to note the rapidity with which changes of temperature are felt at considerable depths, especially in cases when the temperature of the air rises rapidly, accompanied with strong sunshine.

In shallow water the sun's heat raises the temperature much higher than that of deep water, this being obvious from the consideration that nearly the whole of the sun's heat which falls on the surface is utilized in raising the temperature of the shallow layer of water, in other words, it is, so to speak, concentrated through a small depth of water instead of being diffused through a great depth.

Surface Temperature of the Sea.—The importance of a knowledge of this datum of meteorology will be at once recognized when it is kept in view that three fourths of the earth's surface is water, that the temperature of the air resting on this surface is in close relation to the temperature of the surface and that the latter has, through the intervention of the winds direct and important bearings on the temperature of the air over large portions of the land surfaces of the globe. During the years 1859-63 Captain Thomas, while engaged on the survey of the islands on the north west of Scotland, made observations of the temperature of the surface of the sea every hour of the day at all seasons, and with sufficient frequency for the determination of the diurnal range of the temperature of the surface. The daily minimum, 0°.17 below the mean, occurred near 6 A.M., the mean was reached about 11 A.M., the maximum, 0°.13 above the mean, between 3 and 4 P.M., and the mean again shortly before 2 A.M. Thus the daily oscillation of the temperature of the surface of the sea amounted on the north west of Scotland only to 0°.3. In lower latitudes the amount of the daily fluctuation is somewhat larger, but everywhere it is comparatively small, if care be taken to make the observations properly, or at a distance from land, where the influence of the heated or cooled land is not allowed to vitiate the results.

During the voyage of the "Challenger" a complete system of meteorological observations, including the temperature of the surface of the sea, was made every two hours as part of the scientific work of the cruise. These are now being discussed, and the writer of this article is, by permission of the Lords Commissioners of H.M. Treasury, allowed to use such of the results as have been already arrived at.

The diurnal march of the temperature of the surface of the North Atlantic has been determined from observations made on one hundred and twenty six days from March to August 1873 and in April and May 1876, the mean latitude of all the points of observation being nearly 30 N., and the longitude 42° W. The following variations from the mean show the phases of this diurnal oscillation:—

2 A M	-0°24	10 A M	0°06	6 P M	0°26
4 ,,	-0 33	Noon	0 24	8 ,,	0 02
6 ,,	-0 29	2 P.M	0 47	10 ,,	-0 19
8 ,,	-0 12	4 ,,	0 47	Midnight	-0 35

Thus in mid Atlantic, about 30° N lat, where the sun's heat is strong, and at the time of the year when the sun is north of the equator, the diurnal fluctuation of the temperature of the surface is only 0° 80 It is highly probable that nowhere over the ocean does the mean daily fluctuation of the temperature of the surface quite amount to a degree This small daily fluctuation is a prime factor in meteorology, particularly in discussions relating to atmospheric pressure and winds

Temperature of Air over the Open Sea—The following shows the daily march of the temperature of the air over the North Atlantic on a mean of the same one hundred and twenty six days for which the temperature of the sea

2 A M	-1°13	10 A M	0°78		
4 ,,	-1 40	Noon	1 45		
6 ,,	-1 41	2 P M	1 80	10 ,	0 80
8 ,,	-0 21	4	1 56	Midnight	-1 02

The amplitude of the daily fluctuation of the air is thus 3° 21, or nearly four times greater than that of the sea over which it lies During the same months the "Challenger was lying near land on seventy six days The observations made on these days show a greater daily range of temperature of the air than occurred out in the open sea The minimum, -2 05, occurred at 4 A M, and the maximum, 2° 33, at noon, thus giving a daily range of 4° 38 The occurrence of the maximum so early as noon is doubtless occasioned by the greater strength of the sea breeze after this hour, this maintaining a lower temperature Part of the increased range of the temperature of the air as compared with that of the sea was no doubt due to the higher temperature during the day and the lower during the night on the deck of the "Challenger ' as compared with that of the air But, after making allowance for this disturbing influence, it is certain that the temperature of the air has a considerably larger daily range than that of the sea on which it rests The point is one of no small interest in atmospheric physics from the important bearings of the subject on the relations of the air and its aqueous vapour to solar and terrestrial radiation

The hourly deviations from the mean daily temperature of the air at two places, one near the equator and the other in the north temperate zone, and both near the sea, viz, Batavia (6° 8 S lat, 106° 48 E long, mean temperature 78° 7) and Rothesay (55° 50 N lat, 5° 4′ W long, mean temperature 47° 3), are these —

Batavia	Rothesay	Batavia	Rothesay
1 A M -3°2	-1 7	1 P M +5°7	+2°4
2 ,, -3 6	-2 0	2 ,, +5 6	+2 7
3 ,, -4 0	-2 1	3 ,, +5 2	+2 8
4 ,, -4 3	-2 2	4 ,, +4 3	+2 6
5 ,, -4 7	-2 2	5 ,, +3 3	+2 1
6 ,, -4 9	-2 0	6 , +1 9	+1 5
7 ,, -4 3	-1 5	7 ,, +0 6	+0 9
8 ,, -2 2	-0 9	8 ,, -0 4	+0 2
9 ,, -0 5	-0 2	9 ,, -1 2	-0 4
10 ,, +2 8	+0 5	10 ,, -1 8	-0 8
11 ,, +4 4	+1 2	11 , -2 3	-1 2
Noon +5 4	+1 9	Midnight -2 8	-1 5

The times of the four phases of the daily temperature at Batavia are—minimum about 5 50 A M, mean 8 45 A M, maximum 1 20 P M, and mean 7 40 P M, while for Rothesay the same times are 4 30 A M, 9 15 A M, 3 P M, and 8 20 P M At Batavia, where the days and nights are nearly equal during the year, there is little variation in these times through the months, but at Rothesay, where the days are much longer in summer than in winter, there is considerable variation in the times of occurrence of these phases The following table shows the times of the phases for a number of selected places in the northern hemisphere for the two extreme months, January and July —

	January				July			
	Min	Mean	Max	Mean	Min	Mean	Max	Mean
	A M	A M	P M	P M	A M	A M	P M	P M.
Sitka	6 0	9 40	1 30	6 35	3 40	7 40	0 50	7 30
Toronto	6 20	10 0	1 50	9 40	3 50	8 15	3 45	8 10
Philadelphia Havana	6 50	10 0	2 40	8 45	5 0	8 40	3 10	8 0
Archangel	6 0	10 40	1 30	9 0	2 40	8 36	2 50	8 50
Rothesay	5 30	10 10	2 30	8 0	3 30	9 0	3 15	8 50
Oxford	7 20	10 10	2 0	7 0	3 40	8 45	3 10	8 25
Madrid	6 50	10 5	2 40	8 35	4 40	8 50	2 50	8 35
Geneva	6 0	10 0	2 0	8 0	3 15	8 15	2 50	8 10
St Bernard	4 30	8 25	0 55	6 45	3 0	8 10	1 20	7 50
Bogoslovsk	5 30	9 25	1 30	8 15	3 40	7 35	2 5	8 4
Petroalexandrovsk	6 50	9 50	2 35	7 45	4 30	8 20	2 40	8 25
Tiflis	7 10	9 50	2 25	7 50	5 0	9 5	3 10	8 15
Calcutta	6 30	9 35	2 30	8 20	5 30	8 45	0 40	7 30
Bombay	6 0	9 10	2 10	8 5	5 30	9 0	1 30	6 30
Madras	5 40	8 0	0 40	6 45	5 0	8 45	1 25	6 50

During the night in summer the temperature falls continuously from the effects of terrestrial radiation till the earliest dawn, when the daily rise in the temperature sets in owing to the heat reflected from the upper strata of the atmosphere, which have begun to be heated and lighted up by the rays of the morning sun It will be observed that the time of the daily minimum temperature occurs earliest in high latitudes and latest in low latitudes During winter, on the other hand, the minimum temperature takes place in several regions some time before dawn At this season the two chief causes on which changes of temperature depend are the sun and the passage of cyclones and anticyclones, and it is probable that those cases where the minimum occurs markedly before the dawn are, where not occasioned by purely local disturbing causes, due to the mean diurnal times of occurrence of the changes of temperature which accompany the great atmospheric disturbances of cyclones and anticyclones

In July the daily maximum temperature occurs generally from 2 to 4 P M At places, however, near the sea, which are within the immediate influence of the sea breeze, and in places at some distance from the sea, such as Calcutta, where the wind, being essentially a sea wind, attains its greatest daily velocity and the sky at the same time is much clouded, the maximum occurs nearly two hours earlier In high situations, such as the St Bernard hospice, the highest daily temperature also occurs nearly two hours sooner than on the plains below In the winter months the maximum is about an hour earlier than in the summer

In investigating the daily curves of temperature, Sir David Brewster drew several interesting conclusions from them By dividing the daily curve of temperature, deduced from the mean of the year, into four portions, at the points representing the two daily means and the two extremes, he showed that the four portions approximate to parabolas, in which the temperatures are the abscissæ and the hours the ordinates The correspondence between the observed and calculated results is so close that the difference did not in any case exceed a quarter of a degree Fahrenheit. This interesting result is true for places at which the horizon is open all round, so that no shadows of hills, trees, or buildings fall on the places where the thermometers are kept during the day. If a hill rises to the north of the place, by which the sun's rays are never obstructed, it exercises little, if any, influence on the observations but if one or more hills obstruct the rays of the sun after it has risen above the horizon, such obstruction affects the temperature while, and for some time after, the position in which the thermometer is placed is shaded from the sun

Brewster further made the important remark that the mean of observations made at any pair of hours of the same name such as 8 A M and 8 P M, 9 A M and 9 P M, &c, does not differ much from the mean temperature of the day The pairs of hours which approximate closest to the true daily mean are 9 A M and 9 P M, 10 A M and 10 P M, 3 A M and 3 P M, and 4 A M and 4 P M The mean of four hours at equal intervals from each other gives a result still closer to the true mean temperature

In organizing any system of meteorological observation by which it is intended to develop the climatology of the country the determination of the hours of observation is a question of the first importance If only two observations be made daily the best hours are 9 A M and 9 P M or 10 A M and 10 P M and if there be four observations the best hours are 3 and 9 A M and 3 and 9 P M or 4 and 10 A M and 4 and 10 P M If there be three observations the best hours are 9 A M and 3 and 9 P M or 10 A M and 4 and 10 P M but in these cases it is essential that the observation of a minimum thermometer be added to the temperature observations These hours are further strongly recommended by the consideration that they are approximately coincident with the diurnal phases of atmospheric pressure an exact knowledge of which lies at the root of nearly all climatological inquiries The three equidistant hours which have been adopted in several countries, viz 6 A M and 2 and 10 P M are only good as regards the temperature not as regards atmospheric pressure With respect to two daily observations the hours 8 A M and 1 P M which have been adopted in some countries are singularly unsuitable for the furnishing of the observational data required in the development of the climatologies of these countries and what is still more serious in a sense where international co operation is so imperatively demanded these observations cannot be used with any satisfaction in such deeply important inquiries as the comparative climatologies of Europe

The times of occurrence of the highest, lowest, and mean daily temperatures and the amount of the daily range of temperature are in a great degree influenced by the covering or want of covering of the earth s surface on which the air rests When the ground is covered with vegetation, the whole of the solar heat falls on the vegetable covering and as none falls immediately on the soil, its temperature does not rise so high as happens where there is no vegetable covering to shade the surface from the sun The temperature of plants exposed to the sun is not so high as that of exposed soil in the vicinity As regards forests the four diurnal phases of temperature occur later than in the open country and the maximum and minimum are less decided and, since the maximum temperature of the air in forests falls short of the maximum in the open to a considerably greater extent than the minimum under trees is above the minimum in the open it follows that the mean temperature of the air in forests is less than that of the open country adjoining The reason of the difference is that the chilling effects of nocturnal radiation penetrate lower down among the trees than do the heating effects of solar radiation, and as the soil is not heated directly by the sun its temperature is lower, and consequently that of the air over it is also lower A cleared space in a forest, sheltered by the surrounding trees but open to the sun, has a warmer and moister atmosphere in spring and summer and very much moister in autumn than prevails in the open country adjoining, and has also the diurnal differences of range peculiar to a warmer and moister atmosphere

One of the most important elements of climate is disclosed by the difference between the hour of lowest and the hour of highest mean temperature respectively, or, as it is usually expressed, by the daily range of temperature. We have seen that as regards the sea in the north-west of Scotland the difference is only 0° 3 and in the Atlantic about 30° N lat 0° 8, and that probably the diurnal range of temperature of the surface of the sea nowhere amounts to [illegible] In the same part of the Atlantic the daily range of the temperature of the air resting on the ocean is 3° 2, and on the sea near land 4° 4 On advancing on the land, the daily range of temperature rapidly increases, and the rate of increase is greatly augmented when an inland position is arrived at to which any sea breezes that may prevail do not extend

The true daily range of temperature is stated by observations made with maximum and minimum thermometers Generally speaking, the amount of the range increases as the latitude is diminished, and as the distance from the sea is increased, but above all it increases in proportion to the dryness of the climate

The differences of this vital element of climate are strikingly shown in the meteorology of India In the *Report* for 1880 the following are the mean daily ranges of March of that year at a few places at Goa 5° 4 Bombay 11° 2 Kurrachee 23° 5 Jacobabad 37° 4 and Pachbudra (lat 25° 55 N long 72° 18 E) 41° 3 In the last case undoubtedly one of the greatest mean daily ranges of temperature meteorology has yet recorded the mean of the days was 103° 4 and of the nights 62° 1 As March is altogether within the season of the north east monsoon the general drift of the wind over western India where these are situated is from the interior towards the sea subject as regards Bombay and Goa to the influences of the land and the sea breeze On the other hand, in June when the south west monsoon has fairly set in the following are the mean daily ranges of temperature at the same places at Goa 5° 6 Bombay 8° 2 Kurrachee 10° Jacobabad 27° 6 and Pachbudra 24° 1 These show in a striking manner the powerful influence of the moister atmosphere spread over India by the south west monsoon under which the daily range of temperature falls at Kurrachee from 23° 5 to 10° and in the excessively arid climate of Pachbudra from 41° 3 to 24° 1 In these dry climates of the basin of the Indus whilst the rainfall both in March and in June is practically nil, yet the relative humidity of the atmosphere is widely different Thus the humidities for March and June respectively at 4 P M, when the temperature is nearly the maximum for the day are 48 and 77 for Kurrachee 18 and 30 for Jacobabad and 11 and 36 for Pachbudra It is not so much the amount of cloud that determines the degree of fierceness of the sun s heat in these climates as the relative humidity or the dryness of the air as pointed out by Strachey in 1866 Thus at Jacobabad less than half the amount of cloud appears in the sky in June as compared with March but the relative humidities are 30 and 18 and the daily range of temperature 27° 6 and 37° 4 If we except the dry arid wastes of Persia and Arabia, there is perhaps no other region of the globe where the daily range of temperature approaches that of the valley of the Indus Thus in the dry climates of such places as Sacramento (California) in summer it amounts only to about 30° at Madrid to 27°, and Jerusalem 24° In central districts in the south of England it is about 20° farther north it falls to 15° and in the islands in the north whose climate is strictly insular in its character the summer daily range is only 10° In Arctic regions, such as Spitzbergen and Boothia Felix the range in winter varies from 0° 0 to 1° 0, in May, when the sun has reappeared and continues to rise and set it rises to 14° but in July when the sun does not set the range sinks to 10°

But maximum and minimum thermometers not only show the mean daily range of temperature, they are also of great utility in giving observations for the determination of mean temperature The mean temperature may be accepted as the mean of the twenty four hourly observations of the day If with such a system of observation daily readings of the maximum and minimum thermometer be compared, the value of the latter observations in questions of mean temperature may be arrived at Double series of observations of this description have been made at many places The following shows a comparison of the mean of maximum and minimum daily temperatures with means from observations made twenty-four times daily, the former exceeding the latter means in nearly all

	Spring	Summer	Autumn	Winter	Year
Batavia	-0 3	-0 2	-0 2	-0 2	-0 2
Calcutta	1 0	0 7	0 7	0 9	0 8
Peking	0 6	0 6	0 6	0 7	0 6
Nertchinsk.	0 1	0 3	0 6	1 0	0 5
Barnaul	0 5	0 5	0 7	0 8	0 6
Ekaterinburg	0 5	0 7	0 7	0 6	0 6
Tiflis	0 5	0 5	0 5	0 4	0 5
St Petersburg	0 6	0 6	0 3	0 1	0 4
Valentia	0 4	0 5	0 1	-0 1	0 2
Greenwich	0 7	0 8	0 6	0 0	0 4
Rothesay	0 4	0 3	0 3	0 3	0 3

These results show remarkable uniformity, and it may be inferred from them that mean temperatures deduced from maximum and minimum observations are about half a degree above the true mean temperature In general climatological inquiries, observations with these thermometers have the strong recommendation of supplying from observations taken once a day the data for the determination of the mean temperature and mean daily range of localities, to which falls to be added the further advantage of giving results more uniformly comparable for different places than could be afforded by observations made with a common thermometer at any single hour or pair of hours daily

Daily Variation of the Humidity of the Air—The gaseous envelope surrounding the earth is composed of two atmospheres, quite distinct from each other—an atmosphere of dry air and an atmosphere of aqueous vapour The dry air, which consists of oxygen and nitrogen, is always a gas, and its quantity remains constant but the aqueous vapour does not continue permanently in the gaseous state, and the quantity present in the air is by the ceaseless processes of evaporation and condensation, constantly changing If the aqueous vapour remained permanently and unchanged in the atmosphere, or were not liable to be condensed into cloud or rain, the mixture would become as complete as that of the oxygen and nitrogen of the air The equilibrium of the vapour atmosphere, however, is being constantly disturbed by every change of temperature, by every instance of condensation, and by the unceasing process of evaporation Since dry air further materially obstructs the free diffusion of the aqueous vapour, it follows that the law of the independent pressure of the vapour and of the dry air of the atmosphere holds good only approximately The aqueous vapour, however, constantly tends to approach this state Since, then, the independent and equal diffusion of the dry air and the aqueous vapour is, owing to these disturbing causes, never reached, the important conclusion follows that the hygrometer can never indicate more than the local humidity of the place where it is observed Hygrometric observations can therefore be regarded only as approximations to a true indication of the quantity of aqueous vapour in the atmosphere over the place of observation It is, however, to be added that, while in certain cases the amount of vapour indicated is far from the truth, yet in averages, particularly long averages, a close approximation to the real amount is reached if the hygrometer be at all tolerably well exposed and carefully observed

Aqueous vapour is constantly being added to the air from the surfaces of water, snow, and ice, from moist surfaces, and from plants The rate of evaporation increases with an increase of temperature, because the capacity of the air for vapour is thereby increased The atmosphere can contain only a certain definite amount of vapour, according to the temperature, when therefore the air has its full complement of vapour, or when, in other words, it is saturated, evaporation ceases Thus the rate of evaporation is greatest when the air is driest or freest from vapour, and least when the air is nearest the point of saturation. Since currents of air remove the moister and substitute drier air over the evaporating surfaces, evaporation is much more rapid during wind than in calm weather As air expands under a diminished pressure, its temperature consequently falls, and it continues to approach nearer to the point of saturation, or become moister, and, as it contracts under an increased pressure, its temperature rises and it recedes from the point of saturation or becomes drier Hence ascending currents of air become moister with every addition to the ascent, and descending currents drier as they continue to descend Thus as winds ascend the slopes of hills they become moister, but when they have crossed the summit and flow down the other side they become drier in proportion to the descent, and all the changes may be experienced from extreme dryness to saturation in the same mass of air, which all the time has practically had its amount of aqueous vapour neither added to nor diminished

In an atmosphere of air and aqueous vapour perfectly mixed, the elastic force of each at the surface of the earth is the pressure of each In this case the elastic force of aqueous vapour would be the pressure of the whole vapour in the atmosphere over the place of observation This pressure is expressed in inches of mercury of the barometer If we suppose the total barometric pressure to be 30 000 inches, and the elastic force of vapour to be 0 745 inch, the pressure or weight of the dry air, or air proper, would be 29 255 inches, and of the aqueous vapour 0 745 inch From this it follows that the elastic force of vapour may be regarded as indicating the quantity of aqueous vapour in the air at the place of observation, or it may be designated the absolute humidity of the air

The diurnal variation in the elastic force of vapour in the air is seen in its simplest form on the open sea Grouping together all the hygrometric observations made on board the "Challenger on the North Atlantic at a distance from land, from March to July 1873 (eighty four days), we have for that time a mean elastic force of 0 659 inch, and the following diurnal variation —

	Inch		Inch		Inch
2 A M	- 015	10 A M	+ 004	6 P M	+ ·007
4 ,,	- 020	Noon	+ 017	8 ,,	+ 002
6 ,,	- 016	2 P M	+ 020	10 ,,	- 005
8 ,,	007	4 ,,	+ 017	Midnight	+ 003

Hence the minimum (- 020 inch) occurs at the hour when the temperature of the surface of the sea and air resting over it falls to the daily minimum, it then rises to the mean a little after 9 A M, and to the daily maximum (+ 020 inch) at 2 P M, when the sea and air are also near the daily maximum, and falls to the mean shortly before 9 P M

Treating the observations made near land by the "Challenger' during the same months, the following is the diurnal variation disclosed —

	Inch		Inch		Inch.
2 A M	- 003	10 A M	+ 014	6 P M	000
4 ,,	- 009	Noon	+ 011	8 ,,	- 004
6 ,,	- 010	2 P M	+ 007	10 ,,	- 005
8 ,,	- 003	4 ,,	+ 015	Midnight	- 007

The disturbance induced by proximity to land in the distribution of the aqueous vapour in the lower strata of the atmosphere is very striking The maximum and minimum no longer follow the corresponding phases of the temperature of the surface of the sea and of the air The disturbing agents are the sea and land breezes and their effects Under the influence of the land breeze the time of the minimum humidity is delayed till about 6 A.M, and under the influence of the sea breeze and its effects the amount of the aqueous vapour shows a secondary minimum from noon to 2 P M It is to be here noted that this midday minimum occurs at the hours of the day when the surface of the land is most highly heated, the ascending current of heated air rising from it therefore strongest, and the resulting breeze from the sea towards the land also strongest Now it does not admit of a doubt that the diminution in the amount of the aqueous vapour noted on board the "Challenger" near the shore points to an intermixture with the air forming the sea breeze of descending thin air filaments or currents to supply the place of the masses of air removed by the ascending currents which rise from the heated surface of the land At Batavia, on the north coast of Java, and at Bombay, the aqueous vapour is also subject to a secondary minimum during the warmest hours of the day

During the summer months this secondary minimum is best marked at inland places such as Peking, Nertchinsk, Barnaul, Tiflis, and Ekaterinburg, but the time of its occurrence is about two hours later than it is over the North Atlantic Over all these places at this season the ascending current from the heated land in the interior of Asia is very strong On the other hand the lowering of the amount of aqueous vapour scarcely if at all appears as a feature in the summer climate of St Petersburg, and not at all in that of Sitka, where the sea breeze is equally not a constant feature of the climate of the district

In the excessively dry rainless and hot climate of Allahabad, in April the diurnal minimum of the aqueous vapour occurs from 11 A M to 6 P M, the time of absolute minimum being 2 and 3 P M During all other hours of the day the amount of the vapour is above the mean a secondary minimum occurring from 1 to 4 A M At Allahabad, at this time, the absolute maximum vapour pressure occurs at 8 A M Quite similar to this is the diurnal distribution of the aqueous vapour in July at Lisbon and Coimbra, the minimum occurring from 10 A M to 8 P M At this time of the year the climate of this part of the peninsula is hot and dry and the rainfall insignificant in amount As this region lies between the high atmospheric pressure so characteristic a feature of the meteorology of the Atlantic in summer and the comparatively low pressure over the continents southward and eastward, the winds are almost wholly north westerly In this connexion it is instructive to note that the time of maximum vapour pressure is from 4 to 7 A M when the velocity of the wind is near the minimum and the chief minimum vapour pressure from noon to 4 P M when the velocity of the wind and ascending currents reach the daily maximum These results show that the diminution in the vapour pressure during the hours when temperature is highest which characterizes the climates of large tracts of the globe is due to descending air filaments or currents which necessarily accompany the ascending currents that rise from the heated land

At Geneva during the summer months the vapour curve exhibits two daily minima very strongly marked, the one shortly before sunrise and the other from 2 to 4 P M and two maxima one from 8 to 11 A M and the other from 6 to 10 P M and with these the diurnal variations of cloud are in accordance The peculiarly marked features of the vapour curve at Geneva are probably due to the size of the lake, which is large enough to give rise to a decided breeze during the day from the lake all round its shores and during the night to a breeze from the land all round upon the lake On the setting in of the breeze the mass of air composing it having been for some time resting on the lake, is rather moist and thus one of the daily maxima is brought about from 8 to 11 A M As the breeze continues the air supplying it is necessarily drawn from the higher strata of the atmosphere more copiously than in different situations and having thus acquired increased dryness in the descent and having blown over the lake for too short a distance to materially influence its moisture, the air becomes constantly drier till the minimum from 2 to 4 P M is reached The lake breeze thereafter begins to diminish in force, and the air consequently becomes moister till the maximum vapour pressure of the day occurs when the lake breeze dies away and the land breeze has not yet sprung up In the winter months, when these breezes do not prevail the curve of diurnal vapour pressure shows only one maximum and minimum

The *relative humidity* of the atmosphere must not be confounded with its vapour pressure or absolute humidity The relative humidity, or, as it is more frequently called, the humidity, of the air is the degree of its approach to saturation. Complete saturation is represented by 100 and air absolutely free of vapour by 0, the latter state of things never occurring in the atmosphere, a humidity of 10 being of rare occurrence even in such arid regions as those of Arabia The great significance of this element of climate is in its relations to the diathermancy of the air, and consequently to solar and terrestrial radiation It is supposed that perfectly dry air would allow rays of heat to pass through it with at most only a very slight increase to its temperature therefrom Let, however, a little aqueous vapour be added to it, a partial obstruction to the passage of radiant heat is offered, and the temperature of the mixture, or common air, is sensibly raised. Hence, other things being equal, the less the amount of vapour the more are the effects of radiation felt, or the greater the heat of the days and the cold of the nights. The mere amount of vapour in the air does not determine the degree of radiation, but it is the amount of vapour together with a certain temperature—in other words, the absolute and relative humidity of the air taken together—that determines the heating power of the sun and the degree of cold produced by terrestrial radiation

The diurnal variation of the relative humidity is very different from that of the vapour pressure, and presents features of the simplest character The following are the diurnal variations from the mean humidity 80 over the North Atlantic, from the "Challenger" observations in 1873 —

2 A M	+2	10 A M	−1	6 P M	−1
4	+2	Noon	−2	8 ,,	0
6 ,,	+1	2 P M	−3	10 ,,	+1
8 ,,	0	4 ,,	−2	Midnight	+2

Thus the maximum humidity occurs from midnight to 4 A M, or when the daily temperature is at the minimum, and the minimum humidity at 2 P M, when the temperature is at the maximum, the curve of humidity being thus inverse to that of the temperature With two slight modifications this is the diurnal humidity curve for all climates and seasons In the calm which intervenes in the morning between the land and the sea breeze the humidity continues high, or even increases, though at the time the diurnal increase of temperature has already set in The other modification is seen in the humidity curves for Nertchinsk and Barnaul during winter, these curves being not inverse but coincident with the daily curves of temperature In the climates of Central Asia in winter, the amount of vapour is very small, and the increase to the relative humidity during the day is probably occasioned by the more active evaporation from the snow during the day and the stillness of the air favouring the accumulation of aqueous vapour near the surface of the earth

Next to the winds, the aqueous vapour of the atmosphere, in the diverse ways in which in different localities it is distributed through the hours of the day, plays the most important part in giving to the different parts of the globe its infinitely diversified climates

Dew —Dew is deposited over the earth's surface on comparatively clear and calm nights As the cooling by terrestrial radiation continues, the temperature of objects on the surface is gradually lowered to the dew point, and when this point is reached the aqueous vapour begins to be condensed into dew on their surfaces The quantity deposited is in proportion to the degree of cold produced and the quantity of vapour in the air Dew is not deposited in cloudy weather, because clouds obstruct the escape of heat by radiation, nor in windy weather, because wind continually renews the air in contact with the surface, thus preventing the temperature from falling sufficiently low When the temperature is below 32°, dew freezes as it is deposited, and *hoar frost* is produced. The dew-point practically determines the minimum temperature of the night,—because if the temperature falls a little below the dew point the liberation of heat as the vapour is condensed into dew speedily raises it, and if it rises higher the loss of heat by radiation speedily lowers it This consideration suggests an important practical use of the hygrometer, it being evident that by ascertaining the dew point the approach of frost or low temperature likely to injure vegetation may be foreseen and provided against

Diurnal Oscillations of the Barometer—The general character of the daily oscillations of atmospheric pressure is shown by the two curves of fig 2 The solid line gives the mean oscillation for Bombay and the dotted line that for Vienna, these two curves being to a large extent typical of diurnal barometric oscillations in tropical and temperate regions as regards the two maxima and minima and the time of their occurrence

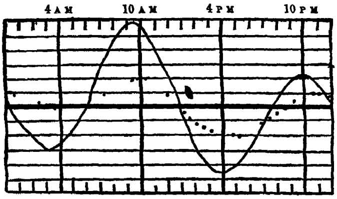


FIG 2 —Daily Oscillations of Atmospheric Pressure

A series of twelve maps of the globe were prepared for June, showing, for all stations whence observations have been obtained, the deviations at noon, 2 P M, 4 P M, &c, Greenwich mean time, from the mean daily pressure and four lines were drawn indicating the positions of the two daily maxima and minima at these hours For fully 30° north and south of the equator the lines of maxima and minima run north and south, but in higher latitudes these directions are changed, and the changes are chiefly conspicuous as regards the A M maximum and the P M minimum Thus, for example at 6 P M (G M T) the line of P M minimum is for the latitude of London near 16° W long, in 30 N lat it is in 35 W long, in which the line runs south as far as 30° S lat its course thence turns south westwards to near the Falkland Islands 60° W long Hence in June the P M minimum occurs about three hours earlier in the Falkland Islands than to the south west of Ireland, thus showing in a striking manner the influence of season on this phenomenon In the middle and higher latitudes in summer, proximity to the sea delays the time of occurrence of the A M maximum and the P M minimum whilst in continental situations the A M maximum occurs much earlier than in lower latitudes, and the P M minimum nearly as late as at places near the sea In cases where the lines of maxima and minima cross a region such as southern and western Europe, whose surface is diversified by large tracts of land and sheets of water, the deflexions are of a remarkable character

The retardation of the time of occurrence of the A M maximum is greatest in situations which, while eminently insular in character, are at the same time not far from an extensive tract of land Of this Holland presents the best example in Europe, and there the A M maximum, which at Paris occurs at 8 A M, does not occur at Utrecht till 9 30 A M, at Amsterdam till 12 30 P M, and at Helder till 2 P M There is thus as regards the same diurnal phenomenon in June a difference of six hours between Paris and Helder Sicily and the south of Italy on the one hand and Madrid on the other present also the most striking contrasts Again at Sitka (56° 50 N lat, 135° W long), which has one of the most truly insular climates in the world, the A.M maximum is delayed to 2 30 P M, whereas at Astoria, ten degrees to southward, it occurs at 9 30 A M, and at Fort Churchill, in Nevada, as early as 7 A.M. There is thus as regards the same phenomenon a difference of 7^h 30^m between Sitka and Fort Churchill

From hourly observations made in this month at the base, the top, and two intermediate points on Mount Washington (N H) it was found that the time of occurrence of the A M maximum at the base of the mountain, which is 2898 feet above the sea, was 8 A M, at 4059 feet, 10 A M at 5533 feet 11 A M, and at the top, 6285 feet, noon Hence, as regards the time of occurrence, the influence of an isolated mountain like Mount Washington brings about a result similar to what is observed in insular situations But the analogy is even closer In insular climates the minimum in the early morning is very greatly in excess of that in the afternoon, and the same relation is observed on the *top* of Mount Washington, where the former is −0 020 inch and the latter −0 004 inch Again in continental climates the minimum in the early morning is much the smaller of the two, and the same relation was observed at the base of the mountain where the observed minima were respectively 0 006 inch and 0 020 inch The differences presented by the daily curve of pressure at the top as compared with that at the base of the mountain have their explanation in the effects which follow the diurnal range of temperature As the temperature is at the minimum at the time of least pressure in the morning the atmosphere is more condensed in the stratum between the base and the top, and consequently the barometer at the top reads relatively lower As the temperature continues to rise during the day, the stratum of air above the base of the mountain expands, thus placing more air above the barometer at the top, so that, while at the base pressure begins to fall at 8 A M, at the top it continues to rise till noon, simply from the mechanical upheaval of the air owing to the higher temperature In the afternoon, when the minimum at the base falls to −0 020 inch, it is only −0 004 inch at the top, this relatively higher pressure at the top being due to expansion from temperature The peculiar feature of the pressure curve at the top is essentially a temperature effect

The diurnal oscillations of the barometer occur alike over the open sea and over the land surfaces of the globe The atmosphere over the open sea, as already shown, rests on a floor or surface subject to a diurnal range of temperature so small as to render that temperature practically a constant both day and night This consideration leads to the vital and all important conclusion that the diurnal oscillations of the barometer are not caused by the heating and cooling of the earth s surface by solar and terrestrial radiation and by the effects which follow these diurnal changes in the temperature of the surface, but that they are primarily caused by the direct and immediate heating by solar radiation, and cooling by nocturnal radiation to the cold regions of space, of the molecules of the air, and of its aqueous vapour These changes of temperature are instantly communicated through the whole atmosphere from its lowermost stratum resting on the earth's surface to the extreme limit of the atmosphere, which the flight of meteors proves to be not less than 500 miles There are important modifications affecting the amplitude and times of occurrence of the four prominent phases of the phenomena observed over land surfaces, the temperature of which is being superheated during the day and cooled during the night, but it is particularly to be noted that the barometric oscillations themselves are independent of any changes of temperature of the floor on which the atmosphere rests.

Let us first look at the phenomena in the simplest form as found in the Pacific, or in the midst of the largest water surface of the globe. The following are the mean variations of pressure from observations made on board the "Challenger," September 1 to 12, 1875, in mean latitude 1° 8′ S. and long. 150° 40′ W., the mean being 29.928 inches:—

	Inch		Inch		Inch
2 A.M.	−0.012	10 A.M.	0.032	6 P.M.	−0.028
4 „	−0.022	Noon	0.006	8 „	0.004
6 „	0.003	2 P.M.	−0.043	10 „	0.013
8 „	0.028	4 „	−0.055	Midnight	0.012

The most striking feature in these oscillations is the amplitude of the range from the A.M. maximum to the P.M. minimum, amounting to 0.087 inch, and the rapidity of the fall from 10 A.M. to 2 P.M. The same feature appears in all means deduced from observations made at least 12° on each side of the equator.

From October 12 to 22, 1875, in mean lat. 35° 1′ S., long. 134° 35′ W., the mean atmospheric pressure was 30.298 inches, and the difference between the A.M. maximum and the P.M. minimum was only 0.036 inch; and from July 12 to 19, 1875, in mean lat. 36° 16′ N. and long. 156° 11′ W., the mean pressure was 30.326 inches, and the difference between the A.M. maximum and P.M. minimum was only 0.025 inch. Thus, with a mean pressure in the Pacific about lat. 35°–36° N. and S. much greater than near the equator, the oscillation is much less, being in the North Pacific less than a third of what occurs near the equator. Similarly, this oscillation is small (or even smaller) in the high pressure areas in the North and South Atlantic as compared with the same oscillation near the equator.

It is well known that aqueous vapour absorbs the heat rays of the sun considerably more than does the dry air of the atmosphere; how much more physicists have not yet accurately determined. Consequently air heavily charged with aqueous vapour will be heated directly by the sun's rays as they pass through it in a greater degree than comparatively dry air is. Now it is shown further on that the prevailing surface winds outflow in every direction from the areas of high mean pressure in the Atlantic and Pacific about lat. 36° N. and S. Since, notwithstanding, the pressure continues high, it necessarily follows that the high pressure is maintained by an inflow of upper currents, and as the slow descending movement of the air connects the inflowing upper currents with the outflowing prevailing winds of the surface, it follows that the air over high pressure areas is very dry, and that it is driest where pressure is highest and the high pressure area best defined. Hence over the best defined anticyclonic regions the air will be least raised in temperature through all its height by the heat rays of the sun.

On the other hand, between these high pressure areas of the great oceans there is a belt of comparatively low pressure towards which the north and south trades pour their vapour unceasingly. The atmosphere of this belt of low pressure is thus highly saturated with aqueous vapour, which rises in a vast ascending stream of moist air to the higher regions of the atmosphere. These equatorial regions thus present to the sun a highly saturated atmosphere reaching to a very great height. It is in these regions therefore that the atmosphere will be most highly heated by the sun's heat rays as they pass through it. One of the most striking facts of meteorology is the suddenness with which this barometric oscillation increases in amplitude on entering on these parts of intertropical regions, and the rapidity with which its amplitude diminishes on advancing on the high pressure regions of the horse latitudes is equally striking. The following are the mean oscillations in the middle regions of the four great oceans about lat. 36° from the A.M. maximum to the P.M. minimum about the time of the year in each case when the sun is highest in the heavens:—South Pacific, 0.036 inch; North Pacific, 0.025 inch; South Atlantic, 0.024 inch; and North Atlantic, 0.014 inch. These amplitudes diminish as the ocean becomes more land-locked with continents, or as the anticyclonic region becomes better defined and currents of air are poured down more steadily from the higher regions of the atmosphere.

If the temperature of the whole of the earth's atmosphere were raised, atmospheric pressure would be diminished, for the simple reason that the mass of the atmosphere would thereby be removed to a greater distance from the earth's centre of gravity. Quite different results, however, would follow if the temperature of only a section of the earth's atmosphere were simultaneously raised, such as the section comprised between long. 20° and 60° W. The immediate effect would be an increase of barometric pressure, owing to expansion from the higher temperature; and a subsequent effect would be the setting in of an ascending current more or less powerful, according to the differences between the temperature of the heated section and that of the air on each side. These are essentially the conditions under which the morning maximum and afternoon minimum of atmospheric pressure take place.

The earth makes a complete revolution round its axis in twenty-four hours, and in the same brief interval the double-crested and double-troughed atmospheric diurnal tide makes a complete circuit of the globe. The whole of the diurnal phenomenon of the atmospheric tides is therefore rapidly propagated over the surface of the earth from east to west, the movement being most rapid in equatorial regions, and there the amplitude of the oscillations is greater than in higher latitudes under similar atmospheric, astronomical, and geographical conditions. Owing to the rapidity of the diurnal heating of the atmosphere by the sun through its whole height, some time elapses before the higher expansive force called into play by the increase of temperature can counteract the vertical and lateral resistance it meets from the inertia and viscosity of the air. Till this resistance is overcome, the barometer continues to rise, not because the mass of atmosphere overhead is increased, but because a higher temperature has increased the tension or pressure. When the resistance has been overcome, an ascending current of the warm air sets in, the tension begins to be reduced, and the barometer falls and continues to fall till the afternoon minimum is reached. Thus the forenoon maximum and afternoon minimum are simply a temperature effect, the amplitude of the oscillation being determined by latitude, the quantity of aqueous vapour overhead, and the sun's place in the sky.

All observations show that over the ocean, latitude for latitude, the amplitude of the oscillations is greater in an atmosphere highly charged with aqueous vapour and less in a dry atmosphere. It is also to be noted that in very elevated situations, particularly in tropical regions, the amplitude is greater proportionally to the whole pressure than at lower levels. This is what is to be expected from the law of radiant heat by which more of the heat rays of the sun is absorbed by the air, and particularly by its aqueous vapour, mass for mass, in the higher than in the lower strata.

When the daily maximum temperature is past, and the temperature has begun to fall, the air becomes more condensed in the lower strata, and pressure consequently at great heights is lowered. Owing to this lower pressure in the upper regions of the air, the ascending current which rises from the longitudes where at the time the afternoon pressure is low flows back to eastward, thus increasing the pressure over those longitudes where the temperature is now falling. This atmospheric quasi-tidal movement occasions the P.M. increase of pressure, which reaches the maximum from 9 P.M. to midnight, according to latitude and geographical position This maximum is therefore caused by accessions to the mass of the atmosphere overhead, contributed by the ascending currents from the longitudes of the afternoon low pressure immediately to westward

As midnight and the early hours of morning advance, these contributions become less and less and at length cease altogether, and pressure continues steadily to fall But between the time when the increase of pressure from the overflow through the upper regions of the atmosphere ceases and the time when pressure increases from the heat rays, direct or indirect, of the returning sun or during the hours of the night when the effects of nocturnal radiation are the maximum, pressure is still further reduced from another cause Radiation towards the cold regions of space takes place, not only from the surface of the globe, but also directly from the molecules of the air and its aqueous vapour The effect of this simultaneous cooling of the atmosphere through its whole height is necessarily a diminution of its tension Since this takes place at a more rapid rate than can be compensated for by any mechanical or tidal movement of the atmosphere from the regions adjoining, owing to the inertia and viscosity of the air, pressure continues to fall to the morning minimum This minimum is thus due, not to the removal of any of the mass of air overhead as happens in the case of the afternoon minimum, but to a reduction of the tension or pressure of the air consequent upon a reduction in the temperature through radiation from the aerial molecules towards the cold regions of space In the open ocean the morning minimum is largest in the equatorial regions, and it diminishes with latitude but the rate of diminution with latitude through anticyclonic and other regions is generally less and more uniform than in the case of the afternoon minimum

The amplitude and times of occurrence of the phases of the diurnal barometric tides are subject to great modifications over the land The amplitude of the oscillation from the morning maximum to the afternoon minimum is greatest where the atmosphere is driest and the sky clearest, and least where the atmosphere is highly saturated and the sky more frequently and densely covered with clouds, being thus generally the reverse of what is observed to take place over the open sea The meteorology of India affords the most striking illustrations of this remark At Bombay in April during the dry atmosphere and clear skies of the north east monsoon the oscillation is 0 118 inch, but in July during the humid atmosphere and clouded skies of the south west monsoon it falls to 0 067 inch In the Punjab where the air is drier it is much greater, rising in exceptional years such as 1892 to 0 187 inch The much greater amplitude of this oscillation on land as compared with the open sea is entirely due to the heating of the earth By this heating of the surface the lower strata of the air become also highly heated and the tension is increased, and, since the air does not expand freely, vertically and laterally, from its inertia and viscosity the barometer rises When, however the resistance is overcome, the ascending current which sets in is stronger owing to its higher temperature Since this higher temperature which has its origin in the superheated surface is in addition to the direct heating of the air by the heat rays of the sun as they pass through it, the morning maximum and the afternoon minimum over land are both more extreme than over the open sea It follows that this oscillation is much larger over land, and largest in climates where insolation is strongest

In places already referred to where the morning maximum is greatly retarded, such as Helder, Sitka, Valentia, and Falmouth the afternoon minimum in the summer months is singularly small,—so small indeed that it does not fall so low as the mean pressure of the day This peculiarity in the diurnal barometric tide is in all probability due to their insular position to the westward of a more or less extensive tract of land, by which a tidal overflow is propagated through the upper regions from the continental towards the insular situations This tidal overflow receives its impulse from the ascending current from the land, which rises sooner and stronger from inland than from insular situations On the other hand, on the open sea, and away from land in regions where the morning maximum and afternoon minimum are both small, the minimum always falls below the mean of the day, and the time of occurrence of the maximum is not retarded as is the case in insular situations A map of deviations from the daily mean pressure of the morning minimum in summer shows as regards the middle and higher latitudes that it is greatest near the sea, and least in inland continental situations Indeed in the interior of the Old World continent the dip in the curve in the early morning is so small that the minimum does not fall below the daily mean pressure, but at most places remains considerably above it The same relations are seen in north western Europe, where the morning minimum is - 0 020 inch at Valentia and Falmouth, - 0 018 inch at Helder, and - 0 012 inch at Amsterdam, whilst at Kew it is only - 0 002 inch From its compact form and relations to the surrounding ocean, the Spanish Peninsula well illustrates the peculiarities of this phase of the pressure The deviations from the daily mean pressure of the morning minimum are at Lisbon - 0 022 inch and Coimbra - 0 011 inch, but at Madrid in the interior + 0 009 inch,—pressure in the last case, just as happens in the interior of Asia, not falling so low as the daily mean

The larger minimum near the sea arises from the higher temperature there during the night as compared with more inland situations from which results a tidal overflow through the upper regions from the sea towards the land, as the temperature of the latter falls lower than the sea during the night The effect of this overflow is to reduce the pressure over those regions whence it proceeds and to increase it in those regions over which it advances The shallowing of the morning minimum is greatest in the higher latitudes of continental climates and most complete at great elevations, where in some cases the minimum vanishes,—in other words, where the amount of aqueous vapour is small and the time is short during which no part of the atmosphere overhead is touched by the sun's rays Since the peculiarity is observable in the curves over nearly the whole continent, appearing even in the low latitudes of Calcutta and Madras, it might be suggested whether we have not evidence here of a vast tidal movement propagated through the higher regions towards that trough like section of the atmosphere as it moves westwards over the continent where the temperature of the lower strata of the air is about the minimum of the day and pressure also about the minimum

Reference has been made under ATMOSPHERE to the smallness of the range from the A M maximum to the P M minimum in the North Atlantic during summer This phase in the diurnal distribution of pressure is represented in fig 3, which shows for June the mean amount of the oscillation by lines of 10, 20, 40, 60 80, and 100 thousandths of an inch, or 0 010 inch, 0 020 inch &c This abnormality begins in March, attains the maximum in June, and terminates in October It is thus confined to the warmer months of the year, and, unlike most meteorological phenomena, is not cumulative, but follows the sun, so that its maximum occurs in June, and not in July as that of the temperature of the air, or in August as the temperature of the sea The smallness of this range over the North Atlantic, which is less than occurs in any other ocean in the same latitudes, is to a large extent caused by the small dip in the diurnal curve of the afternoon minimum

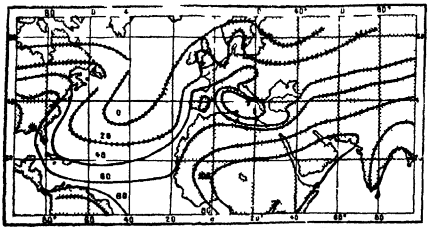


FIG 3 —Oscillations of Barometer for June

If the map of the distribution of pressure over the globe for July be examined (fig 17) it is seen that this part of the Atlantic is occupied by a well defined area of high mean pressure,—higher indeed than occurs at any season over any ocean, and it is shown below that out of this area the surface winds blow in all directions But, since air is constantly being drained out of this region by the wind without diminishing the pressure, it follows of necessity that the high pressure must be maintained by accessions of air received from above through the upper currents Now the regions whence such accessions can come are the upper currents which have their origin in the ascending currents that rise from the heated plains of Africa, Europe, the belt of calms, and the two Americas surrounding the North Atlantic It is evident that the major portion of each day's overflow of air from the continents through the upper regions of the air upon the Atlantic, whether this overflow takes place by convection currents or from a tidal movement similar to what has been already described, will take place during mid afternoon In other words, the overflow will occur about the time of the afternoon minimum of the Atlantic, thus diminishing the dip of this minimum, and so producing the abnormally small range now under examination It is in favour of this view that the abnormality follows the sun's course and is not cumulative, and is felt also on both sides of th Atlantic, even although the weather on the east side is dry and all but rainless, and on the west moderately moist and characterized by a rather copious rainfall It is also full of significance that the peculiarity is most strikingly seen in that part of the ocean of the globe which is closely hemmed in by large masses of land

Influence of the Moon on Atmospheric Pressure—Fifteen years' hourly observations have been made at Batavia and discussed by the late Dr Bergsma in their relation to the lunar day, which was assumed in the calculations to commence with the time of the upper transit of the moon The result of the inquiry is that atmospheric pressure at Batavia has a lunar tide quite as distinctly marked as the ordinary diurnal barometric tide, except that its amplitude is much less The four phases are these —

1st max	+0 0022	inch at lunar hour	1
1st min	−0 0021	,	7
2d max	+0 0025	,	13
2d min	−0 0024	,	19

The lunar tide has the important difference that its phases follow the moon's apparent course much more closely than the ordinary diurnal fluctuations of the barometer follow that of the sun The two maxima occur about the 1st and 13th, and the two minima about the 7th and 19th, whereas these four daily phases of the diurnal barometric fluctuation occur with respect to the sun's apparent course from one to six hours later It is interesting to note that in the higher latitudes in inland situations during winter, or at times and in situations where the disturbing influences of temperature and humidity tend towards a minimum, the times of occurrence of the four phases of the daily oscillation of the barometer approximate to those of the daily lunar atmospheric tide

Since a distinct lunar tide is traced to the attractive influence of the moon, it follows that the attractive influence of the sun will enter as one of the several causes which determine the phases and amplitude of the diurnal barometric curve It also follows from the much less attractive influence of the sun than that of the moon on the earth's atmosphere that the effects of the sun's attraction on the pressure will be wholly concealed by the much larger effects of the other forces concerned in determining the diurnal oscillation, except in the case or cases where the variation in the fluctuation is small at 1 and 7 A M and 1 and 7 P M Now at places north of lat 45° N the variation at 1 A M is small during the winter, and it is a singular fact that some years ago Rykatchew of St Petersburg drew the attention of meteorologists to the existence at these northern stations of a faintly marked third maximum and it is further of importance to remark that, at many places where on the mean of years the third maximum is scarcely or not at all marked, it appears in the mean of some of the separate years Thus, though it does not appear in the mean of the twenty years ending 1873 at Greenwich for January, it appears in nine of the individual years It is highly probable that this maximum, which may be named Rykatchew's maximum from its discoverer, is due to the attractive influence of the sun, its amplitude and time of occurrence being in accordance with such a supposition

Diurnal Variation of the Force of the Wind—During the three and a half years cruise of the "Challenger," ending with May 1876, observations of the force and direction of the wind were made on 1202 days, at least twelve times each day,—650 of the days being on the open sea and 552 near land The observations of force were made on Beaufort's scale 0–12, being the scale of wind-force observed at sea The mean diurnal force of the wind on the open sea and near land respectively is shown

FIG 4 —Diurnal Force of Wind at Sea and near Land

in fig 4, where the figures on the left are Beaufort's scale, and those on the right the equivalents in miles per hour The solid line shows at the different hours of the day the mean force on the open sea, and the dotted line the mean force near land

As regards the open sea it is seen that the diurnal variation is exceedingly small, there being two apparent slight maxima, about midday and midnight respectively On examining, however, the separate means for the North and South Atlantic, North and South Pacific, and the Southern Ocean, there is no uniform agreement observable among their curves, the slight variations which are met with being different in each case It follows therefore that the force of the winds on the open sea is subject to no distinct and uniform diurnal variation The difference between the hour of least and greatest mean force is less than a mile per hour

Quite different is it, however, with the winds encountered by the "Challenger" near land, the force of the wind there giving a curve as pronouncedly marked as the ordinary diurnal curve of temperature The minimum occurs at 2 to 4 A M and the maximum from noon to 4 P M, the absolute highest being at 2 P M The curves constructed for each of the five oceans from the observations near land give one and the same result, or a curve closely accordant with the curve of diurnal temperature The differences between the hours of least and greatest force are as follows —Southern Ocean 6½ miles, South Pacific 4½ miles, South Atlantic 3¼ miles, and North Atlantic and North Pacific 3 miles per hour

In the case of each ocean the velocity of the wind on the open sea is considerably in excess of that near land, but in no case does the maximum velocity near land, attained about midday, reach the velocity of the wind on the open sea The 650 daily observations on the open sea give a mean hourly velocity of 17½ miles, whereas the 552 near land give a velocity of only 12½ miles per hour The difference is greatest at 4 A M, when it amounts to upwards of 6 miles an hour, but is diminished by the rising temperature till at 2 P M it is less than 3 miles an hour

At Mauritius which is situated within the south east trades the minimum velocity of the wind is 9 7 miles per hour occurring from 2 to 3 A M from which it rises to the maximum 18 5 miles from 1 to 2 P M, the influence of the sun being thus to double the wind's velocity At Batavia situated in a region where the mean barometric gradient is much smaller the differences are still more decided From 1 to 6 A M 85 per cent of the whole of the observations are calms whereas from noon to 2 P M only 1 per cent are calms In all months the minimum velocity occurs in the early morning when the temperature is lowest and the maximum from 1 to 3 P M when the temperature is highest the mean minimum and maximum velocities being to each other as 1 to 21 At Coimbra the mean maximum hourly velocity is five times greater than the minimum hourly velocity in summer whereas in winter it is only about a half more At Valentia in the south west of Ireland, one of the windiest situations in western Europe the three summer months of 1878 gave a mean hourly velocity of 13 3 miles per hour the minimum oscillating from 10 to 11 miles an hour from 9 P M to 6 A M and the maximum exceeding 16 miles an hour from 11 A M to 5 P M The absolute lowest hourly mean was 10 miles at 11 P M and the highest 18 miles at 1 P M the velocity about midday being thus nearly double that of the night Many observations might be added to these including those published by Hann Koppen Hamberg and others which go to establish the fact that the curves of the diurnal variation of the velocity of the wind generally conform to the diurnal curves of temperature The curves are most strongly marked during the hottest months and the maximum velocity occurs at 1 P M or shortly thereafter being thus before the time of occurrence of the maximum temperature of the day and the minimum in the early morning, or about the time when the temperature falls to the lowest The rule also holds good with all winds whatever be their direction The exceptions to this rule are so few and of such a kind that they are probably to be attributed to causes [illegible] less of a local character

Hann has shown, for a number of places in northern Europe, that with a clear sky the velocity is doubled from the minimum to the maximum, with a sky half covered the velocity is three fourths greater, and with a sky wholly covered the velocity is only a half more On the other hand at the strictly inland situation of Vienna, with a clear sky the velocity is double and with a sky half covered it is two thirds greater, but with a covered sky the diurnal varia

of a velocity not exceeding 30 kilometres an hour show a mean diurnal increase from 11 kilometres at 6 A M to 16 8 at 1 P M but that winds of velocity exceeding 30 kilometres an hour exhibit only a faintly marked and irregular increase of velocity during the day

In offering an explanation of this remarkable fact regarding the diurnal variation in the velocity of the wind in all climates, it is to be remarked that the minimum velocity occurs when terrestrial radiation and its effects are greatest, but the increase of the velocity closely follows the sun, and the maximum is reached nearer the time the sun crosses the meridian than perhaps any of the other maxima or minima of meteorology which are dependent on the sun's diurnal course It is also to be noted that the winds over the open sea are practically uninfluenced by solar and terrestrial radiation, for there the diurnal curve of variation in the force of the wind is all but a straight line On nearing land, however, the wind's force exhibits a diurnal curve of variation as distinctly marked as, and bearing a close resemblance to, the analogous curve of temperature, while on the land itself these features become still more decidedly pronounced Lastly, the amount of the diurnal variation of the temperature of the surface of the sea is less than a degree, whereas over all land surfaces the diurnal variation of the temperature is large, even where the ground is covered by vegetation, and enormously large over sandy wastes

From this it follows that, so far as concerns any direct influence on the air itself, solar and terrestrial radiation exercise no influence on the diurnal increase of the velocity of the air with the increase of its temperature,—or, if any influence at all, such influence must be altogether insignificant, as is conclusively shown by the wind observations of the "Challenger" over each of the five great oceans of the globe The same observations show that on nearing land the wind is everywhere greatly reduced in force The retardation is greatest during the hours when the daily temperature is at the minimum, and it is particularly to be noted that, though the temperature rises considerably, no marked increase in the velocity sets in till about 9 A.M., when the temperature has begun to rise above the daily mean From this time the increase is rapid (see fig 4), the maximum is reached shortly after the period of strongest insolation, and the velocity falls a little (but only a little) during the next three to five hours, according to season, latitude, and position, and falls again to near the minimum shortly after the hour when the temperature is at the mean Even at the maximum, the velocity near land falls considerably short of the velocity which is steadily maintained over the open sea by night as well as by day

The period of the day when the wind's velocity is increased is practically limited to the hours when the temperature is above the daily mean, and the influence of this higher temperature is to counteract to some extent the retardation of the wind's velocity resulting from friction and from the viscosity of the air The increase in the diurnal velocity of the wind is in all probability due to the superheating of the surface of the ground and to the consequent ascensional movement of the air, tending to counteract the effect of friction and of viscosity between the lowermost stratum of the air and the ground It is of importance in this connexion to keep in view the fact that in cloudy weather a temperature much higher than might have been supposed is often radiated from the clouds down upon the earth's surface,[1] which accounts for the phenomenon of the diurnal variation in the wind's velocity occurring frequently also in cloudy weather On the other hand during the night, when terrestrial radiation is proceeding, the temperature of the surface falls greatly, and instead of an ascensional movement in the lower stratum of the air there is rather a tendency towards a descensional movement (if the wind be light there is an actual movement) of the lowest air stratum down the slopes of the country, and since the friction between the wind and the surface of the earth is thereby increased the diurnal velocity of the wind falls to the minimum during these hours (see also p 156)

---

[1] *Journal of Scottish Meteorological Society*, vol ii p 280.

Among the most marked exceptions to the general rule of the diurnal distribution of wind force may be cited the bitterly cold furious blasts of wind encountered in narrow valleys in such mountainous regions as the Alps during clear and comparatively calm nights These are simply the out rush of the cold air poured into the upper basins of the valleys by the descensional currents from the slopes which the chilling effects of terrestrial radiation set in motion On the other hand, the air of the valleys becomes heated and expands during the day, thus giving rise to a warm wind blowing up the valleys, which, on account of the vapour it carries with it from the lower levels, frequently covers the higher slopes and tops of the mountains with cloud and drizzling rain

Diurnal Variation in the Direction of the Wind—In all climates near seas and other large sheets of water, where the distribution of atmospheric pressure is tolerably equable, or the barometric gradient small, and the sun heat moderately strong, land and sea breezes are of daily occurrence In such places a breeze from the sea gradually sets in in the morning, which gradually rises to a stiff breeze during the heat of the day and again towards evening sinks to a calm Soon after this a breeze sets in from the land, blows strongly seaward during the night, and dies away in the morning, giving place to the sea breeze as before These breezes are occasioned by the surface of the land being heated in a much higher degree than that of the sea during the day, the air over the land being thereby made lighter ascends, and its place is supplied by the cooler air of the sea breeze drawn landward, and partly also by descending currents, as shown by the humidity observations of the "Challenger," which indicate increasing dryness when the sea breeze is strongest Again during the night the temperature of the land and of the air over it falls below that of the sea, and the air of the land thus becoming heavier and denser flows over the sea as a land breeze As the best marked and most frequently occurring cases of the sea breeze begin some distance out at sea and gradually approach the land, it is very probable that, as suggested by Blanford, the ascending heated air flows seaward as an upper current and that the increased barometric gradient thus caused largely accounts for these breezes

Sea and land breezes are thus determined by the relative positions of the land and its coasts subject to a further modification arising from the rotation of the earth Thus on the [illegible] Gulf of Lyons the sea breeze from the south [illegible] and dies away as a west wind while the land breeze from the north gradually veers to north east and dies away [illegible] On the coast of Algeria [illegible] north to north east and dies away in the east [illegible] land breeze veers to south west and dies away in the west Sea breezes also occur in such [illegible] latitudes as that of Scotland when the weather conditions are favourable The conditions are presented when an anticyclone overspreads the country with its accompanying fine settled weather small variation in the distribution of atmospheric pressure clear skies and frequently strong sunshine Under these conditions the following are the veerings of the wind off the coast of Berwickshire In the morning the wind is north west till about 10 A M, when it veers to north falling all the time till finally it sinks to a calm A little before noon it springs up from north east or east, veers to south-east from 2 to 6 P M, it continues till 7 P M, about which time it veers to south and then south west, diminishing in force and finally sinking to a calm. About sunset it springs up from west, veering to north west during the night, where it continues till the following morning The wind thus virtually makes the round of the compass, is strongest from north-west and south east and weakest at north east and south west, being thus strongest when its course is perpendicular to the line of coast.

The observations made by the "Challenger" in the region of the north east trades in 1873 show a small diurnal variation in the direction of the wind, the variation being from E 47° 5 N at 2 to 6 A M to E 56° N at 10 A M to 2 P M, the variation being thus 8° 55 towards north during the hottest hours of the day At Mauritius observatory, which is several miles from the sea, the daily period in the direction of the wind is from E 22° 15′ S at 4 A M, being the most southerly point, to E 7° S at 1 P M, and thence back to E 22° 15 S at 4 A M The diurnal variation is 15° 15, and thus the influence of the sun impresses on the wind at this observatory a more truly easterly character

At the Austrian naval station at Pola, near the head of the Adriatic, the daily variation in the direction of the wind is well-marked Starting from a point east of south at 5 A M, it gradually veers round to westward the most westerly point, almost due west, being reached at 5 to 6 P M after which it gradually shifts back to its starting point in the morning Here we have evidently a diurnal wind system different from that of the land and the sea breeze Pola is situated near the south western extremity of the peninsula of Istria and the direction in the early morning of east by south is the direction the wind would take if a small anticyclone overspread the peninsula and the direction from the west in mid afternoon is the direction the wind would have at Pola if the peninsula were occupied by a small cyclone with the lowest pressure in the centre Now the influence of solar radiation is to form, through the ascending current from the heated land a diminution of pressure over the land —in other words what is essentially a cyclone On the other hand, during the night the influence of terrestrial radiation is to generate through the cooling of the land and the air resting above it a relatively higher atmospheric pressure in the interior of the peninsula with its characteristic system of out blowing winds

At Coimbra in July 1878 the diurnal variation of the wind's direction was from W 49 37 N at 2 to 6 A M to W 33° 15 N. at 4 to 6 P M the amount of the variation being thus 16° 22 in the direction of west At Valentia in the south west of Ireland, during the summer months of 1878 the diurnal variation of the wind's direction was from W by S at 7 to 9 A M to S W by W at 5 to 7 P M The variation was thus from a point nearly south to a point nearly south west or through nearly 45° in the direction of west On the other hand at Aberdeen during the same months of 1878 the diurnal variation of the wind's direction was from S W at 6 to 7 A M to S by E at 12 to 4 P M the variation being thus 56° from south west in the direction of east through south Attention is here drawn to the exactly opposite ways in which the diurnal veering or shifting of the wind takes places at Valentia and Aberdeen but particularly to the important circumstance that in each case the diurnal changes in the wind's direction which actually occur are precisely those that would take place on the supposition that during the hottest hours of the day an ascensional movement of the air sets in from the heated lands of the British Islands and that an in draught takes place all round which with the descending currents makes good the loss caused by the up draught Thus then both the diurnal increase in the wind's velocity and the change in its direction which observation shows to take place during the hottest hours of the day are traced to the same cause viz the heating of the surface by the sun the heating of the lowest stratum of air resting on the surface and the ascensional movements which are the necessary result

It is instructive to note that at Nukuss at some distance to the south of the Sea of Aral where the summer direction of the wind is northerly the north component is at the daily maximum at 4 P M, having shifted into this direction from north east, where it is at 9 A M Much or nearly everything remains to be done in working out this problem in its practical details as one of the important elements of climatology with the view of arriving at some definite knowledge of the influence of physical configuration and different vegetable coverings of the surface on radiation and on the velocity and direction of the wind

Diurnal Variation in the Amount of Cloud—Mists and fogs are visible vapours floating in the air near the surface of the earth, and clouds are visible vapours at a considerable height These forms of visible vapour are all produced by whatever lowers the temperature of the air below the dew point,—such as radiation from the molecules of the atmosphere towards the cold regions of space, the simple expansion of the air of ascending currents, the mixing of cold air with air that is warm and moist, and the cooling of the air in contact with the surface of the earth when its temperature has been lowered by nocturnal radiation

The forms of clouds are endless Since clouds are subject to certain distinct modifications from the same causes which produce other atmospheric phenomena, the face of the sky may be regarded as indicating the operation of these causes, just as the face of man indicates his mental and physical states Hence the importance of the study of clouds, and hence the necessity of a nomenclature of clouds as the basis of accurate and comparable observations An adequate nomenclature of clouds is still a desideratum Luke Howard s classification which continues to hold its ground as a provisional nomenclature, was proposed by him in 1803, and by it clouds are considered as divided into seven kinds Of these, three are simple forms the *cirrus*, the *cumulus*, and the *stratus*, and four intermediate or compound, the *cirro cumulus*, the *cirro-stratus*, the *cumulo-stratus*, and the *cumulo cirro-stratus*, *nimbus*, or *rain cloud*

The cirrus cloud consists of wavy, parallel, or divergent filaments, which may increase in any or all directions It is the cloud of the least density, the greatest elevation, and the greatest variety of figure It is probable that the particles composing it are minute crystals of ice or snow flakes The cirrus is intimately connected with the great movements of the atmosphere and it is solely from the movements of the cirrus that we have any direct knowledge of the upper currents of the atmosphere In recent years much has been done, particularly by Professor Hildebrandsson of Upsala and Clement Ley in investigating the relations of this cloud to storms and other changes of weather

The cumulus is the name applied to those convex or conical heaps of clouds which increase upwards from a horizontal base They are generally of a very dense structure, are formed in the lower regions of the atmosphere, and are carried along by the aerial current next the earth They form the tops of the ascending currents which rise from the heated ground and have a diurnal period so well marked that they are often named the "cloud of the day The form of stratus comprehends those mists and fogs which in the calm evening of a warm summer day make their appearance in the bottom of valleys and over low lying grounds, and sometimes spread upwards over the surrounding country like an inundation they have an equally well marked daily period and are frequently called the ' cloud of night The cirro cumulus is made up of small roundish masses lying near each other, and quite separated by intervals of sky It may be considered as formed from the cirrus by the fibres of that cloud breaking as it were and collapsing into roundish masses, thus destroying the texture but retaining the arrangement of that cloud This singularly beautiful cloud is commonly known as a mackerel sky, and is of most frequent occurrence during dry warm summer weather The cirro stratus consists of horizontal masses thinned towards the circumference, bent downwards or undulating, and either separate or in groups Since this cloud has great extent and continuity of substance but little perpendicular depth or thickness, it is the cloud which most frequently fulfils the conditions for the phenomena of coronæ, solar and lunar halos, parhelia or mock suns and paraselenæ or mock moons The cumulo stratus is formed by the cirro-stratus blending with the cumulus, or spreading underneath it as a horizontal layer of vapour The cumulo-cirro-stratus, or nimbus, is the well known rain cloud, which consists of a cloud or system of clouds from which rain is falling. At a considerable height a sheet of cirro-stratus cloud is extended, under which cumulus clouds drift from windward, these rapidly increasing unite and appear to form one continuous grey mass from which the rain falls The breaking up of the lower grey mass indicates that the rain will soon cease When a rain cloud is seen at a distance, cirri appear to shoot out from its top in all directions, and it is observed that the more copious the rainfall the greater is the display of cirri The cirrus, cirro cumulus, cirro stratus, cumulo stratus, and nimbus are connected more or less closely with the great atmospheric movements of the cyclone and anticyclone In what follows here only the amount of sky covered will be taken into account, and not the species of cloud covering

The diurnal variation in the amount of cloud in the sky on the open sea is very small The following are the means of two hundred and seventy seven days' observations on board the "Challenger, stated in percentages of sky covered –

2 A M	59	10 A M	58	6 P M	57
,,	59	Noon	56	8 ,,	57
6 ,,	62	2 P M	58	10 ,,	57
8	62	4 ,,	59	Midnight	57

Two maxima are here indicated, the one about or shortly after sunrise and the other in the early part of the afternoon and two minima, the one at noon and the other from sunset to midnight The difference between the extremes is only 6 per cent of the sky

At Batavia the daily maximum is from 6 to 11 P M and the minimum from 8 to 11 A M the extremes being 52 per cent at 9 A M and 69 per cent at 7 P M —a difference of 17 per cent Of four daily observations at Mauritius the maximum is 50 per cent. at 1 P M and the minimum 38 per cent at 6 A M At Coimbra, observations of clouds have been made five times daily and six years results give the maximum 63 per cent at 9 P M and the minimum 52 per cent at 9 A M At this place, during July and August the greatest amount of cloud occurs at 6 P M and in these months the rainfall at Coimbra is very small The minimum is more pronounced at 9 A M than at any other period in winter this phase occurs about four hours later At the continental situation of Vienna during the warm months of the year the maximum is at 2 P M with a secondary maximum about 6 A M , and the minimum from 10 P M to 2 A M but during the cold months the maximum is at 6 A M and the minimum during the evening and night In the Rocky Mountains the chief maximum 57 per cent is at 3 P M with a secondary one 50 per cent at 5 A M , and the chief minimum [illegible] at [illegible] A M and a secondary one 29 at 11 P M At Helsingfors the maximum of cloud occurs from 10 A M to 2 P M , and the minimum from 10 P M to 2 A M

Much yet remains to be done with regard to the determination of the diurnal variation of cloud, but from the above one or two deductions of a general character may be drawn A maximum occurs in the morning and continues till shortly after the sun has risen and this maximum is more decidedly pronounced over the open sea than over land Its appearance is without a doubt due to the general cooling of the atmosphere through its whole height by terrestrial radiation and its disappearance to the heating of the air which commences about sunrise Then follows one of the diurnal minima which continues till midday, or a little later in other words, it continues till, owing to the diurnal heating of the air by the sun, the ascending current has fairly set in The period of this ascending current marks the second maximum which during the warmer months is larger than the morning maximum over land The cumulus is the characteristic cloud of this maximum These clouds are merely the summits of the ascending currents which rise from the heated land, where the aqueous vapour is condensed in cloud by the expansion which takes place with increase of height

These cumulus clouds throw a not unimportant light on the behaviour of the ascending currents which rise from the surface when heated by the sun,—inasmuch as they point to the fact that the current ascending from the surface is broken up and thereafter grouped into separate well-defined ascending currents, which are marked out and overtopped by these cumuli, and further it is probable, from their well defined position, that the air composing the ascending currents is not only warmer but also more humid than the air in the clear interspaces at the same heights It may also be regarded as highly probable that it is down through these clear interspaces that the descending air filaments shape their course in their way to take the place of the air molecules that ascend from the heated surface of the earth

The secondary minimum occurs from about sunset onwards during the time of the P M maximum of atmospheric pressure In a highly saturated atmosphere, which is so characteristic a feature of many tropical climates at certain seasons, this time of the day is remarkable for the amount of cloud, and it is during those seasons and hours that heat-lightning, or lightning without thunder, attains its annual and diurnal maximum period, which is from six to eight hours later than that of thunderstorms The morning maximum, shortly before and after sunrise, has two quite distinct and characteristic clouds accompanying it One of these is the cumulo stratus, which is a consequence of the cooling of the atmosphere through all its height by nocturnal radiation As the colouring of the cloudlets is often singularly fine, it has been a favourite theme with poets of all ages and climes The other, which results from the cooling of the surface of the earth by terrestrial radiation and thence of the lower stratum of the atmosphere, is quite different, being a low creeping mist, appearing first in low lying situations, and gradually extending upwards as the temperature falls Fog is a well known form of this cloud, having its diurnal maximum in the morning and early part of the day

Diurnal Variation in the Amount of the Rainfall —From the sixteen years during which hourly observations of the rainfall were made at Batavia Dr Bergsma has given a table showing the diurnal variation, of which the following shows how much per cent of the total daily amount fell every two hours —

Midt to 2 A M	8 7	8 A M to 10 A M	5 5	4 P M to 6 P M	13 5
2 A M „ 4 „	6 4	10 „ „ Noon	6 3	6 „ 8 „	10 5
4 „ „ 6 „	6 1	Noon „ 2 P M	9 5	8 „ „ 10	7 4
6 „ „ 8 „	5 2	2 P M „ 4 „	12 2	10 „ „ Midt	8 7

The diurnal curve of rainfall is thus very distinctly marked at Batavia The minimum is from 6 to 10 A M and the maximum from 2 to 6 P M,—10 7 per cent falling during the four hours ending 10 A M, but 25 7 per cent in the four hours ending 6 P M

The observations were arranged and averaged by Dr Bergsma with the view of seeing how far the phases of the moon influence the rainfall The results for the eight phases of the moon, beginning with new moon showing the mean amount of rain in twenty four hours during the seventeen years ending 1880, are these —0 243 0 236 0 193, 0 181 0 212 0 183 0 189 and 0 203, and daily mean 0 205 inch The influence of the moon s phases on the rainfall at Batavia is thus quite decided from these seventeen years for while the mean daily rainfall is 0 205 inch it rises at full moon to 0 243 inch from which time it gradually falls to 0 181 inch at the third octant, rises to 0 212 inch at the fourth octant, falls again to 0 183 inch at the fifth octant, and finally rises to the maximum at the time of new moon

At Coimbra where the rainfall has been observed every two hours for the six years ending 1881 the means show a minimum of 3 08 inches from midnight to 2 A M a maximum of 4 03 inches from 2 to 4 A M a second minimum of 3 20 inches from 10 A M to noon, and a second maximum from 2 to 4 P M These four phases of the rainfall are pretty nearly accordant with the four phases of the barometric pressure the maximum periods being near the times of minimum pressure, and the minimum periods near the times of maximum pressure The rainfall at Philadelphia shows a decided maximum at 6 P M and minimum at 3 A M At Vienna during the summer half of the year there are three maxima maximum, which is nearly double of each of the other two, occurring from 2 to 4 P M, and the chief minimum from 3 to 6 A M At this place the number of hours of rain has been recorded, showing two maximum periods, the first from 2 to 8 A M and the second from 4 to 7 P M Since the time of maximum amount indicates a number of hours for the fall under the mean of the day, it follows that the showers from 2 to 4 P M are often very heavy At Prague the chief maximum is from 2 to 6 P M and the minimum from 1 to 6 A M At Zechen the maximum is from 2 to 7 P M, with a secondary maximum from 5 to 8 A M, and the minimum from midnight to 4 A M At Bern the maximum fall is from 7 P M to midnight Twenty one years observations at Calcutta show the maximum occurrence of rainfall during the rainy season from June to October to be from 11 A M to 6 P M, the absolute maximum being from 2 to 3 P M and the minimum from 9 P M to 1 A.M, and during the hot dry season from March to May the maximum is from 5 to 9 P M, and the minimum from midnight to 9 A M

The data already collected show the general occurrence of a diurnal maximum from about 11 A M to 6 P M, and this feature of the curve is particularly well seen in the rainfall of continental climates during the summer half of the year A marked diminution of the rainfall is very generally observed from about sunset to midnight, when the diurnal amount of cloud in many climates falls to the minimum, and the evening maximum of atmospheric pressure takes place The time of the morning minimum pressure from about 2 to 6 A M is, curiously, strongly marked in some places with an increase, while in others is as strongly marked with a diminution, in the rainfall The "Challenger" observations show that the occurrence of rain on the open sea is inversely as the temperature 684 days' observations giving 96 cases from 9 to 4 P M, and 135 from midnight to 2 A M, these being the minimum and maximum periods

Diurnal Variation of Thunderstorms —It has just been remarked that a prominent feature of the diurnal rainfall in continental climates during the summer months is the increased rainfall from about 11 A M to 6 P M, and the Vienna observations point to unusually heavy falls occurring at these hours This is caused by the rains which accompany the thunderstorms of these regions The following table gives for the hours of the day the times of occurrence of thunderstorms at Ekaterinburg in the Ural Mountains during the fourteen years ending 1872 —

	April	May	June	July	Aug	Sept	Year
Midnight to 1 A M			5	5	5		15
1 A M „ 2 „			1	5	2		8
2 „ „ 3 „			1	4	1		6
3 „ „ 4 „			1	2	3		6
4 „ „ 5 „			2	1	1		4
5 „ „ 6 „			3	3			6
6 „ „ 7 „			2	3			5
7 „ „ 8 „	1		5	2	2		10
8 „ „ 9 „	1		4	4	1		10
9 „ „ 10 „	1		6	7	5		19
10 „ „ 11 „	1		8	12	4		25
11 „ „ Noon	1	2	14	30	5	1	53
Noon „ 1 P M	3	4	19	25	5	4	60
1 P M „ 2 „	2	8	21	29	12	2	74
2 „ „ 3 „	3	10	22	35	15	4	89
3 „ „ 4 „	3	6	26	45	20	1	101
4 „ „ 5 „	2	5	24	33	9		73
5 „ „ 6 „	1	6	25	30	11	2	75
6 „ „ 7 „	2	7	15	20	10		54
7 „ „ 8 „	2	5	16	20	9		52
8 „ „ 9 „	2	6	14	14	6		42
9 „ „ 10 „	2	3	8	10	5	1	29
10 „ „ 11 „		1	6	6	5		18
11 „ „ Midnight		1	7	6	8		22
Sums	27	64	255	351	144	15	856

Hence the thunderstorms at this place have a diurnal period as strongly marked as any other meteorological phenomena, and in this respect Ekaterinburg is fairly representative of extratropical continental climates during

during the six months from October to March The mean of the six hottest months shows the maximum to take place from 3 to 4 P M and the minimum from 4 to 5 A M, these being the times of occurrence of the two minima of pressure At this season, however, the morning minimum pressure is but faintly marked in such climates as those of Siberia During the twelve hours from 9 A M to 9 P M, when the temperature is above the daily mean, 717 of the whole number occurred, thus leaving only 139 for the twelve hours when the temperature is below the daily mean The great majority of the thunderstorms occur during the part of the day when the ascensional movement of the air from the heated ground takes place, and they attain the maximum when the temperature and this upward movement are also at the maximum Owing to the westerly winds from the Atlantic which prevail over Europe and western Siberia during summer the maximum rainfall of the year occurs over this extensive region in this season, and the importance and significance of the inquiry into this element of climate lie in the fact that the greater portion of the summer rains is discharged over these regions by the thunderstorm The "Challenger observations on the open sea show the maximum occurrence of thunderstorms to be from 10 P M to 8 A M, 22 being observed during these ten hours and 10 during the other fourteen hours of the day,—a result which suggests that over the ocean terrestrial radiation is more powerful than solar radiation in causing vertical disturbances in the equilibrium of the atmosphere

Atmospheric vapour and ascending currents thus play an important part in the history of these thunderstorms Where the climate is dry and rainless, like that of Jerusalem in summer, thunder is altogether unknown On the other hand, where during a particular season an anticyclone with its vast descending current in the centre remains over a region, as happens over the centre of the old continent during the winter, over that region thunder is equally unknown during that season Further, in such places as Lisbon and Coimbra, where the summer rainfall is small and its occurrence infrequent, thunderstorms become less frequent, and the hours of their occurrence are later in the day than they are before and after the dry season

The thunderstorms at Mauritius call for special notice There are two maxima in the diurnal curve the larger from noon to 4 P M and the smaller from 3 to 6 A M which are near the times of the barometric minima and two minima from 9 P M to 1 A M and from 8 to 10 A M these being near the times of the barometric maxima But the important point as regards the thunderstorms of Mauritius is that for twelve years none were recorded in June and July one only in August one in September and three in October The annual period of the thunderstorms of this island extends from near the end of October to the middle of May or during the time of the greatest rainfall practically none occurring during the rest of the year But rain continues to fall during the four months of no thunder the mean monthly rainfall being then about 2 inches falling however in September to 1 37 inches During these four months therefore there is in the air the aqueous vapour and these being dry months there is the condition of ascending currents There appears however to be then wanting another element which seems essential to the electrical manifestations of the thunderstorm viz the conditions which give masses of descending cold air along with the ascending current of warm moist air During the months

belt of calms between the two trade winds to stretch in a slanting direction from Madagascar to Ceylon As long as this state of things occurs with more or less frequency the conditions of a descending cold current of large volume are provided and thunderstorms occur But during June July, August and September when atmospheric pressure is low in Central Asia and there is an unbroken increase of pressure from Asia southwards to Mauritius and while Mauritius remains in the heart of the south east trades the conditions of descending cold currents of any considerable volume are not present and thunder is there unknown at that season

Now in situations which afford the three conditions of aqueous vapour, ascending currents and descending cold currents, whilst the diurnal and annual periods are quite distinctly marked the phenomena are more uniformly distributed through the hours of the day and months of the year than elsewhere Pola and Fiume at the head of the Adriatic being shut in and encompassed by lofty Alps, are illustrations At Fiume the greater maximum occurs from 11 A M to 4 P M and the smaller from 2 to 4 A M and the minima from 10 P M to 1 A M and 5 to 9 A M While during the twelve hours the temperature is above the mean of the day from May to September the number of the thunderstorms here was 245 for the nine years ending 1879 the number during the twelve hours the temperature is under the mean was 185 The comparatively large number during the colder hours of the night is no doubt due to the warm moist atmosphere of this confined sea and the close proximity of the Alps

There is still another set of conditions favouring the development of thunderstorms in certain climates which the observations made at Stykkisholm in the north west of Iceland illustrate During the fourteen years ending 1879 there occurred here twenty three thunderstorms but there was only one in the six warm months from April to September in other words the thunderstorms of this climate are essentially winter phenomena Further, of the twenty three hours in which they occurred only three were at a time of the day when the sun was above the horizon viz, twice in March and once in September in other words the thunderstorms of Stykkisholm are nocturnal phenomena It is instructive to observe that in the north and north west of Scotland thunder occurs most frequently during the night and in winter whereas in central southern and eastern districts it occurs most frequently during the day and in summer —the thunderstorms in the former case approximating in type to those of Iceland and in the latter to those of Ekaterinburg A little reflexion shows that in north western Europe it is during winter and during night that warm moist ascending and cold dry descending currents are most frequently brought into close proximity during the great Atlantic storms of the season and it is at the changes of wind humidity, and temperature accompanying the passage of the centres of the cyclones that the thunder peals are heard On the other hand in the east and south of Scotland it is during the hot months of the year that these ascending columns of warm moist air and descending columns of cold dry air are most frequently brought together and there accordingly thunder with the heavy rains which accompany it is of most frequent occurrence from 11 A M to 5 P M from May to September These essentially different types of thunderstorms have been classed by Mohn as heat thunderstorms and cyclonic thunderstorms

Given an initial difference of electric potential, it is easy to understand from the effects which follow the sudden extraordinary condensations of the aqueous vapour that take place how the most violent thunderstorms are produced The difficulty is to account for the production of the initial difference of electric potential,—how, for example, in the same great aerial current of the south west monsoon, this difference of potential is produced in the molecules of aqueous vapour at Calcutta but not in the aqueous vapour at Mauritius It is to the physicist that meteorologists still look for the explanation

Diurnal Period in the Occurrence of the Whirlwind, Waterspout, Dust Storm, and Tornado—Whirlwinds, waterspouts, dust storms, and tornadoes are essentially the same, differing from each other only in their dimensions, their intensity, or the degree in which the moisture is condensed into visible vapour, while the hailstorm and the rainstorm are simply the manner and degree of the precipitation accompanying them In several important respects they differ widely and radically from cyclones (see ATMOSPHERE, vol iii p 33) The largest tornadoes are of so decidedly smaller dimensions when compared with the smallest cyclones as to admit of no shading of the one into the other Cyclones occur at all hours of the day and night, whereas whirlwinds and tornadoes show a diurnal period as distinctly marked as any in meteorology Finally, cyclones take place under conditions which involve unequal atmospheric pressures or densities at the same heights of the atmosphere, due to inequalities in the geographical distribution of temperature and humidity but whirlwinds occur where for the time the air is unusually warm or moist, and where consequently temperature and humidity diminish with height at an abnormally rapid rate Cyclones are thus phenomena resulting from a disturbance of the equilibrium of the atmosphere considered horizontally, but whirlwinds and tornadoes have their origin in a vertical disturbance of atmospheric equilibrium

Among the most remarkable of the tornado swept regions of the globe are certain portions of the United States and to the examination of these the meteorological service of the States has given special attention by a systematic, careful and minute observation of the attendant phenomena and the destructive effects The tornadoes of the last eighty seven years numbering about six hundred have been classed under the different States where they are reported to have occurred and fig 5 shows this relative distribution over the States The areas of greatest frequency are at long distances from each other That part of the great basin lying west of the Mississippi, including the States of Iowa, Missouri, Kansas, and Nebraska, is the region in which tornadoes are most frequent Tornadoes occur at all seasons, being most frequent, however, from April to September, and least frequent in December and January

The hour of occurrence of one hundred and sixty two of the tornadoes is given in the official report as follows —

Midt to 2 A M	-	8 A M to 10 A M	1	4 P M to 6 P M	52
2 A M ,, 4		10 ,, ,, Noon	7	6 ,, ,, 8 ,,	17
		Noon ,, 2 P M	13	8 ,, ,, 10 ,,	7
		2 P M ,, 4 ,,	47	10 ,, ,, Midt	4

Thus the diurnal period of tornadoes is analogous to the period for temperature wind velocity, and thunderstorms The atmospheric conditions which appear invariably to precede the formation of the tornado are violent contrasts of temperature and humidity immediately to the north and south of the path to be traversed by the storm It is highly interesting to observe from fig 5 that the region of most frequent occurrence of tornadoes is the region where a large number of the cyclones of the United States appear to originate (and the same region Loomis has shown to be remarkable for violent contrasts of temperature occurring within limited spaces and times) and that as appears in the regions of the Alleghanies they decrease in frequency with height

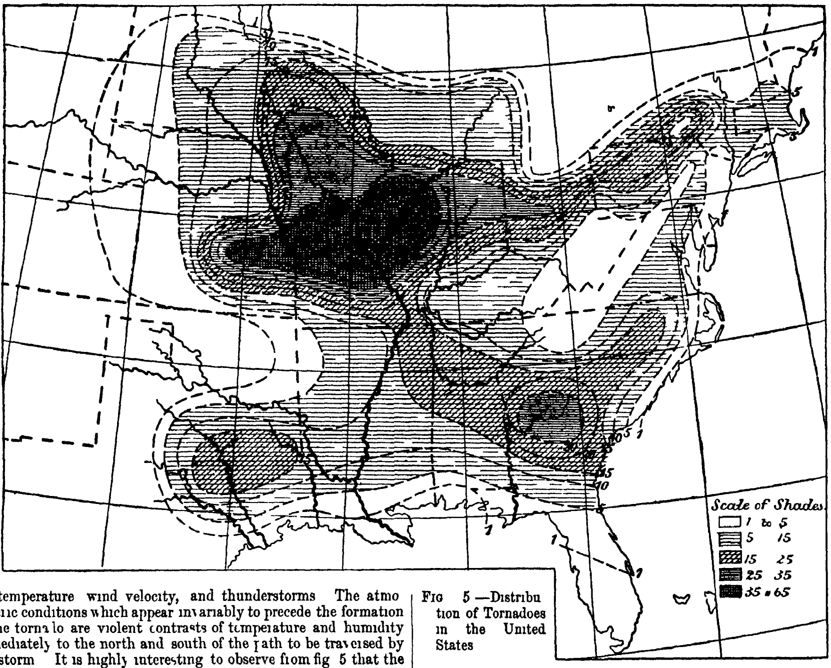


FIG 5 —Distribution of Tornadoes in the United States

Fig 6 shows the waterspout in different aspects A black cloud covers the sky, from which a projection is let down in the form of an inverted cone, as at A, which continues to increase and extend downwards The sea immediately beneath is soon thrown into violent agitation, showing that the whirling movement which began in the clouds has extended to the sea, and is doubtless continuous throughout, though the portion of the column from A downwards is not yet made apparent by the condensation of its contained vapour into cloud As the whirling movement of the column becomes more intensely developed, the increased rapidity of the gyrations brings about increased rarefaction of the air within, with the inevitable result of increased condensation of the vapour into cloud downward The protrusion of the cloud and its extension downwards are thus not due to the descent of vapour from the clouds, but to the visible condensation of the vapour of the spirally ascending air-currents arising from an increasing rarefaction due solely to the accelerated rate of the gyrations, the condensation being analogous to that of the cloud seen in exhausting an air pump

Under each of the columns of fig 6 the surface of the sea is seen to be more or less heaped up, as well as in violent agitation, showing that atmospheric pressure immediately under the gyrating columns is less than it is all round On land, when the tornado passes directly over a dwelling house or other closed building, it often happens that the whole building, walls and roof, is thrown outward with great violence, the wreckage presenting the appearance of a sudden explosion, proving that atmospheric pressure outside the building was instantaneously and largely reduced, and the building shattered to fragments by the expansion of the air within It is in this way that the tornado does some of its most dreadful work

The wind of the tornado reaches a velocity probably never equalled in cyclones During the Ohio tornado of February 4, 1842, large buildings were lifted entire from their foundations, carried several rods through the air, and then dashed to pieces, some of the fragments being carried distances of 7 and 8 miles, and large oaks nearly 7 feet in girth were snapped across like reeds This tornado swept on its course at the rate of 34 miles an hour, and at one place did its fearful work in the brief space of a minute The tornado which passed over Mount Carmel (Illinois), June 4, 1877, swept off the spire, vane, and gilded ball of the Methodist church, and carried it bodily 15 miles to north eastward The velocity of the ascending currents which kept this heavy object suspended in the air for 15 or 20 miles must have been very great

Of the tornadoes the progressive courses of which were recorded, 310 advanced towards N E, 38 towards S E, 16 towards E N E, 14 towards E, 7 towards N N E, 5 towards E S E, and 3 towards S S E The course is thus always towards some easterly direction, the great majority being towards the north east The velocity of their onward movement varied from 12 to 60 miles an hour, the average being 30 miles an hour The time occupied in passing a particular spot varied from 10 seconds to half an hour the mean time being nearly six minutes and a half The width of the path of destruction marked with debris and other relics of the violence of the tornado varied from 40 to 10,000 feet, the average being 362 yards The direction of the whirling movement of the tornado was invariably from right to left, or the opposite of the movement of the hands of a watch, resembling in this respect the vorticose movement of cyclones in the northern hemisphere The passage of the tornado cloud is often described as accompanied with remarkable noises, which observers variously characterize as terrible, deafening, a terrific crash, the roar of a thousand trains of cars, or the uproarious din of innumerable pieces of machinery

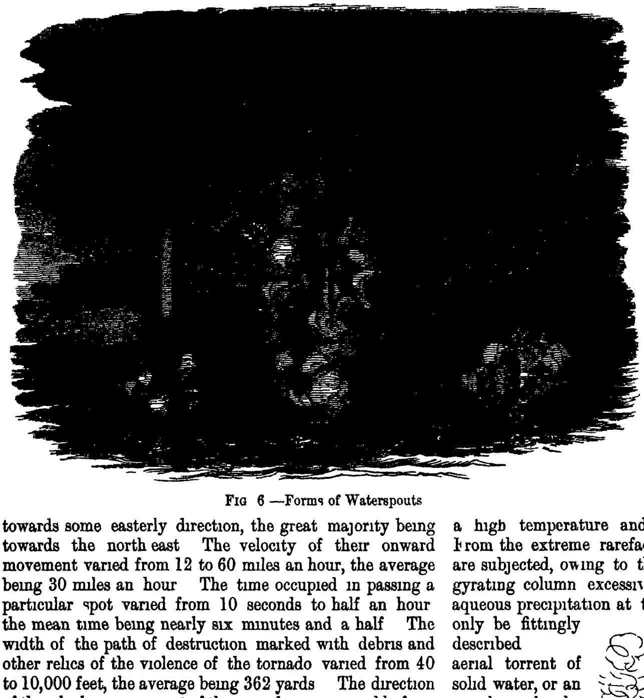


Fig 6 —Forms of Waterspouts

The usual position of the gyrating columns of cloud is vertical, but occasionally a curving form or slanting direction is assumed It is probable that to these latter forms many stationary or slowly moving dangerous squalls are to be referred, which spring up with unexpected suddenness in lakes and arms of the sea in mountainous regions

The dust storm of India, Arabia, and Africa is a well marked type of the whirlwind Previous to the outbreak of a dust storm the air is unusually calm and sultry, just as happens in the case of the tornado The simplest form of the dust storm is that of a tall aerial column of sand moving onwards, and drawing into itself, as it whirls round in its course, dust and other light bodies within the sweep of the strong air-currents which blow along the surface of the ground and converge vorticosely round the base of the column A form commonly seen is shown in fig 7, which represents several dust columns grouped together, each whirling independently round its own axis with incurving air currents at the base, while the whole group of columns is borne bodily forward, and presents striking aspects as the forms and relative positions of the columns are changed The importance of the observations made on dust storms as leading to a correct understanding of the whirlwind consists in this that it affords conclusive evidence that there is a strong inflow of the air along the surface of the ground all round vorticosely towards the base of the whirlwind, and that these same inflowing air currents afterwards ascend through the air along the central axis of the whirlwind, carrying with them the evidence of their ascent in the visible solid particles of dust, sand, and other light objects they whirl up with them in their ascending course

Owing to the extreme dryness of the air currents involved in the dust storm, the rarefaction generated by the rapidity of the gyrations is insufficient to produce condensation of the aqueous vapour in the interior of the column Quite different, however, is it with waterspouts and tornadoes, where, in the great majority of cases, the air near the surface before being drawn into the ascending vortex is of a high temperature and near the point of saturation From the extreme rarefaction to which these air currents are subjected, owing to their sudden ascent in a rapidly gyrating column excessive condensation follows, with an aqueous precipitation at times so astonishing that it can only be fittingly described aerial torrent of solid water, or an aerial avalanche of hail and ice

Certain tracts of the ocean included within what may be called permanent anticyclones, or where atmospheric pressure is higher than all round, are characterized by an absence or comparative absence of rain These regions are also remarkable for clear skies and strong sun heat Similarly small anticyclonic areas occurring between or in the vicinity of cyclones are characterized by dry air and clear skies, and it is under these conditions that the strongest sun heat is felt When, as repeatedly

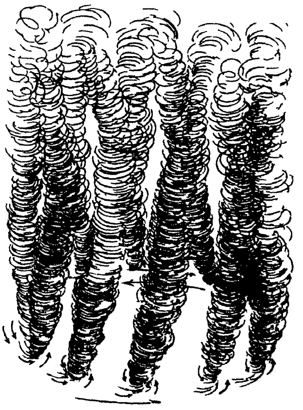


Fig 7 —Dust Storm

happens in the warmer months of the year, anticyclones remain practically stationary for some time, the lowermost strata of the air become abnormally heated,—thus bringing about a vertical disturbance of the equilibrium of the atmosphere out of which whirlwinds originate It is under these conditions that white squalls or fair weather whirlwinds occur, the originating cause of this special form being the great dryness of the air due to its place in the anticyclone, and the abnormally rapid diminution of temperature and humidity with height owing to the strong insolation through the clear dry atmosphere The clouds accompanying the white squalls are at a great height, but the commotion and boiling of the sea under them and following them as they drift onwards show that the squalls are true whirlwinds, the vapour column of the waterspout not being formed solely on account of the extreme dryness of the air which ascends the columns The white squall accompanies fine weather, and its appearance is sudden, its duration brief, and its destructive power at times so dreadful that it has been known to strip a ship of every sail and mast in a few seconds, and leave it rolling a helpless log amidst the tremendous sea which follows it In sailing through such regions a close lookout should be made, particularly when the weather looks singularly fine, the skies beautifully clear, the air calm or nearly so, and the temperature and moisture of the air on board the vessel noticeably high

Diurnal Period of Hail —The hail here referred to is round, hard, and compact, and in the form of clear or granular ice, the hailstones sometimes being found when broken across to be composed of alternate layers of these two states of ice The following figures show the number of times it has occurred during the different hours of the day at Coimbra during the last six years —

Midt to 2 A M		8 A M to 10 A M	3	4 P M to 6 P M	3
2 A M „ 4 „		10 „ „ Noon	20	6 „ 8 „	1
		Noon „ 2 P M	15	8 „ 10	0
		2 P M „ 4 „	13	0 „ „ Midt	0

A diurnal period is thus well marked at Coimbra, where forty-eight out of the fifty nine cases have occurred from 10 A M to 4 P M This period is essentially the same as those calculated for a large number of places in representative climates, care having been taken to limit the inquiry to the particular hail described above The important point to be noticed in the diurnal period of hail is that the time of maximum is about two hours earlier than the maximum period of thunderstorms The maximum period for the thunderstorm is when the ascending current from the heated land is at its greatest force for the day, but the maximum period for hail is some time before the ascending current has fully established itself, or at that time of the day when the vertical disturbance of the atmosphere is greatest,—in other words, when atmospheric temperature and vapour fall with height at a much greater rate than the normal In the higher latitudes hail falls almost exclusively during the warmer months of the year In regions where the summer climate is practically rainless no hail falls, and where the rainfall is small and at distant intervals few cases of hail occur Thus at Coimbra, where little rain falls in summer, hail was recorded as having fallen only once in the six years during the four dry hot months from June to September

All hail is probably connected immediately with whirlwinds, more or less developed, and it is when the hailstorm is one of the phenomena attendant on the tornado or on a great thunderstorm that it assumes its most destructive form The theory of the formation of hail has been stated by Ferrel in his *Meteorological Researches for the Use of the Coast Pilot*, part ii p 85 The vapour carried aloft by the gyrations of the tornado is below a certain height condensed into cloud and rain, but above that height into snow Let the raindrops formed below be carried up into the snow region by the powerful ascending currents of the tornado and be kept suspended there a little while, and they become frozen into hail If now these be thrown quite outside the gyrations of the tornado, they fall to the earth as a shower of compact homogeneous hailstones of clear ice of ordinary size If, however, they are caught in the descent and carried in toward the vortex by the inflowing currents on all sides, they are again rapidly carried aloft into the freezing region A number of such revolutions of ascent and descent may be made before they fall to the earth While high up in the snow region, the hailstones receive a coating of snow, but, while traversing the region lower down where rain yet unfrozen is carried up, they receive a coating of solid ice Thus alternate coatings of snow and ice are received, and the number of each sort indicates the number of revolutions described before the hailstones fell to the ground When the nucleus is composed of compact snow, as is generally the case, the hailstone had its origin high up in the snow region as a small ball of snow, or soft hail (*Graupel* in German and *gresil* in French), but when it is composed of clear ice throughout it was formed in the rain region, carried up into the snow region and there frozen, and immediately afterwards fell to the ground

MONTHLY, ANNUAL, AND IRREGULARLY RECURRING PHENOMENA

The Temperature of the Sea —Figs 8 and 9, representing the distribution of the temperature of the surface water of the ocean for the two extreme months February and August, are reproduced chiefly from *The Wind and Current Charts for Pacific, Atlantic, and Indian Oceans*, published by the British Admiralty in 1872

In February (fig 8) the temperature of the surface of the sea falls to the annual minimum over the northern hemisphere, and rises to the maximum in the southern hemisphere The course of the isothermals more closely follows the latitudes in the Pacific, Indian, and South Atlantic Oceans, but the divergence from the latitudes is great and striking over the North Atlantic The wider and more open the ocean the more does the distribution of the temperature approach the normal, and the more confined the ocean the greater is the divergence from the normal The key to the anomalous distribution of the temperature of the ocean is furnished by the charts of the distribution of atmospheric pressure and the prevailing winds of the globe So far as observation has gone it would appear that the surface currents are practically altogether caused by the prevailing winds over the respective oceans subject to such deflexions in their courses as are occasioned by the land

In the southern hemisphere the currents on the west side of the Indian Ocean flow southwards along the east coast of Africa and, since the currents here pass from lower to higher latitudes, the temperature along the whole extent of this coast is raised considerably above the normal On the other hand, since the currents on the west coast of Africa flow from south to north—in other words, from higher to lower latitudes—the ocean currents which impinge on this coast have a temperature much under the normal The winds and currents on the coasts of South America are precisely analogous to those of Africa, and the distribution of the temperature of the sea is also similar The temperature of the ocean on the east coast of that continent is for the same latitudes everywhere higher than on the west coast Even in the smaller continent of Australia the same law holds good

In the northern hemisphere a different distribution of the temperature of the sea is seen at this season In the Atlantic the temperature is very much higher on the west of Europe than on the east of America On the east of America from Wilmington to Boston occur the most rapid transitions in the mean temperature of the ocean anywhere on the globe the temperature falling in that short distance from 70° to 30°, whereas on the eastern side of the Atlantic these isothermals pass Cape Verd Islands and Spitzbergen respectively In the winter months the prevailing winds of the east side of North America are north westerly, whilst in the central and eastern portion of the Atlantic they are south westerly, thus pouring along the east coast of America the icy currents of the Arctic regions, but over the central Atlantic and along the western shores of Europe the warm waters of southern climates The easterly and south easterly winds of Scandinavia in winter lower the isothermals along these coasts A striking feature of the winter isothermals of the Atlantic is the singularly high temperature along the centre stretching from Spitzbergen towards the south west and extending in a modified degree as far south as the West Indies In the Pacific this feature of the mid ocean temperature is much less pronounced, and the excess of temperature on the west of America over what occurs in the same latitudes of eastern Asia is not so great as the difference observable between the two sides of the Atlantic

The highest mean temperature in February (85°) occurs in the Indian Ocean to the south west of Sumatra, and there is a patch the temperature of which is 84° to the north of Madagascar The highest means in the Atlantic are 82° in the north east angle of the Gulf of Guinea and 81° off the north east coast of Brazil In the Pacific the highest are 83° to the north of the Fiji Islands and 81° near the Marshall Islands

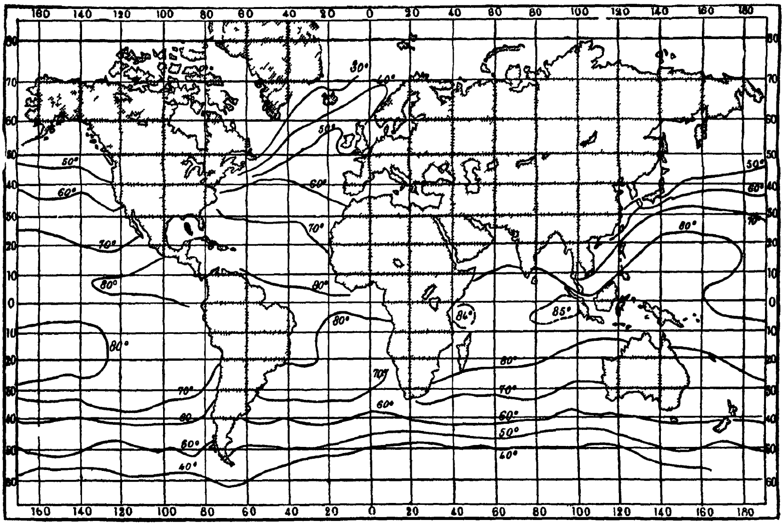


FIG 8 —Isothermals of the Surface of the Sea for February

In August (fig 9) the southern half of the Red Sea shows a mean temperature of 90° being the highest mean recorded for the ocean anywhere at any season Patches showing a summer mean of 85° occur in the Chinese Sea to the east of Tonquin in the Bay of Bengal to the east of southern India, about Socotra, and to the west of Central America But the most extensive regions of high temperature are in the west of the Pacific between long 165° E and the Philippines northward nearly to Japan and southward to New Guinea, and the Gulf of Mexico and the adjoining part of the Atlantic as far east as long 57° W A patch of remarkably low temperature occurs in the Pacific a little to the west of Galapagos where the mean is only 70° being 10° lower than what occurs anywhere else near the equator at this season

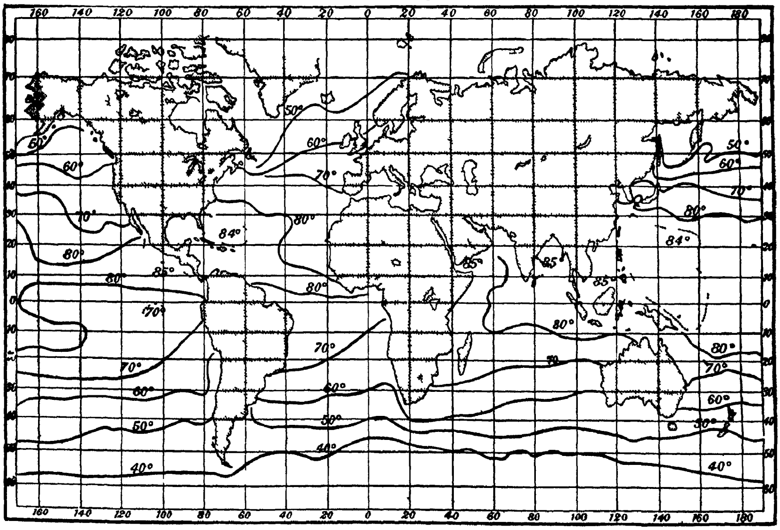


FIG 9 —Isothermals of the Surface of the Sea for August

The influence of currents is strongly expressed in the temperature of all the oceans In the south of Asia the monsoons are S W, S and S E Under the impulse of these monsoonal winds an extensive surface drift of the waters of the equatorial regions is carried northwards towards southern Asia, and consequently very high temperatures characterize these seas in summer. It is instructive to note the effect on the temperature of the sea resulting from the region of high atmospheric pressure in the North Atlantic at this season. Out of this anticyclonic region the winds blow in all directions, giving rise to surface currents flowing in the same directions. Thus to the west of Africa the winds and currents are from north to south, and hence the temperature of this part of the ocean is abnormally reduced. On the other hand, on the west side of this high pressure area the prevailing winds and currents are from south to north, and it will be seen that the temperature of the whole of the region swept by the southerly winds is abnormally raised. On the north side of the area the winds and currents are westerly as far as about long. 35° W., and over that space the isothermals follow the parallels of latitude. Farther to eastward and northward the prevailing winds become south westerly, thus propelling northwards along the western shores of Europe by oceanic surface drifts, the warmer waters of southern latitudes. Meanwhile the currents of cold water and ice drifts from the Arctic regions keep the temperature off America to the north of Newfoundland at a figure considerably lower than is observed in any other region in the same latitudes. In August similar relations exist as in January between the east and west coasts respectively of South Africa, South America, and Australia, all of which are readily explained by the charts of mean atmospheric pressure and the resulting prevalent winds.

One of the most striking facts of ocean temperature is that the temperature of the Southern Ocean from about 50° to 60° S. lat. is practically the same in January and August, a circumstance due chiefly to the magnificent icebergs of that ocean.

The Temperature of the Land.—In regions where the rainfall is distributed through all the months of the year, and where snow covers the ground for only a small part of the year, the mean temperature of the soil nearly equals that of the air. But when the year is divided into wet and dry seasons, and when snow lies during a considerable portion of the year, the mean annual temperature of the soil may be above or below that of the air. The greatest difference between the temperature of the soil and that of the air occurs where the surface of the ground is covered during several months with snow. Snow is a bad conductor of heat, and thus obstructs the free propagation of the cold produced by radiation downwards into the soil, and the escape of heat from the soil into the air. In this way, over a considerable portion of the Russian empire, the temperature of the soil is considerably in excess of that of the air. Thus at a place 120 miles south of Archangel the temperature of the soil is 10° higher than that of the air, and at Semipalatinsk it is 9° higher.

The daily changes of temperature only affect the soil to depths of about 4 feet. The precise depth varies with the degree of the sun heat and with the nature of the soil. Similarly the heat of summer and the cold of winter give rise to a larger annual wave of heat propagated downwards, the amplitude of which diminishes with the depth till it ceases to be perceptible. Principal Forbes showed from observations on the Calton Hill, Edinburgh, that the annual variation is not appreciable lower than 40 feet below the surface, and that under 25 feet the change of temperature through the year is small. The depth at which the annual variation ceases, or where the temperature remains constant, is a variable depending on the conductivity and specific heat of the soil or rock, but particularly on the difference between the summer and winter temperatures. The rate at which the annual wave of temperature is propagated downwards is so slow that at Edinburgh, at a depth of 24 feet, the highest annual temperature does not occur till January 4, and the lowest till about July 13, thus reversing the seasons at this depth. At Greenwich, at a depth of 25½ feet, these phases of the annual temperature occur on November 30 and June 1.

Professor Everett in the *Report of the British Association* for 1879 has summarized the results of the observations of underground temperature. The temperature of the surface of the ground is not sensibly influenced by the flow of heat from below upwards, but is determined by atmospheric and astronomical conditions. The temperature gradient is defined as the rate of increase of the temperature downwards, and it may be taken as averaging one degree Fahrenheit for every 50 or 60 feet, the exact rate in particular cases being very variable. Thus the temperature gradient of the soil is about five times steeper than the temperature gradient of the air. The temperature gradient is steepest beneath gorges and least steep beneath ridges, and hence the underground annual isothermals are flatter than the uneven surfaces above them. This is the case even with the uppermost isothermal of the soil, and the flattening increases as we pass downwards until at a considerable depth they become horizontal. Where the surface of the ground and the isothermal surfaces beneath it are horizontal, the flow of heat is vertical, and the same quantity of heat flows across all sections which lie in the same vertical. In this case the flow across a horizontal area of unit size is equal to the product of the temperature gradient by the conductivity, if the latter term be used in an extended sense, so that it includes convection by the percolation of water, as well as conduction proper, and hence, in comparing different strata in the same vertical, the gradient varies in the inverse ratio of the conductivity.

Since the effects of the cold generated by nocturnal radiation mostly accumulate on the surface of the earth, but the effects of solar radiation are spread to some height by ascending currents from the heated ground, it might be expected that the annual temperature of the surface layer of the soil would be lower than that of the air resting over them. Observations prove that such is the case. Springs which have their sources at greater depths than that to which the annual variation penetrates have a constant temperature throughout the year, and if they do come from a depth considerably greater than this they may be regarded as giving a very close approximation to the mean annual temperature of the place. The temperature of cellars is also very near the mean annual temperature of the locality, at any rate this temperature may be secured for cellars anywhere.

Distribution of Temperature in the Atmosphere.—Of the larger problems of meteorology, the distribution of temperature in the atmosphere over the land surfaces of the globe was the first that received an approximate solution (by Humboldt). But as regards the ocean, which comprises three fourths of the earth's surface, the question of the monthly and annual distribution of temperature in the atmosphere over it can scarcely yet be said to have been seriously looked at. The isothermals of the temperature of the atmosphere which cross the oceans continue still to be drawn essentially from observations made on the islands and along the coasts of these oceans. The first step towards the solution of this vital problem in climatology and other branches of meteorology is the construction of charts of mean monthly temperature of the surface water of the sea over all parts of the ocean from which observations for the purpose are available. In prosecuting this line of inquiry, excellent work has been done by the Meteorological Office as regards parts of the Atlantic between the tropics and the ocean to the south of Africa, and also by the Dutch, French, and German meteorologists. With such charts it would not be difficult, by a careful comparison during the same intervals of time between the temperature of the surface of the sea and that of the air resting over it, to construct monthly charts of the temperature of the atmosphere over the oceans of the globe.

In this connexion the whole of the observations of the temperatures of the air and sea made on board the "Challenger" have been examined, and sorted into one hundred and seventy four groups according to geographical position, and the differences entered on a chart of the route of the expedition. In the Southern Ocean between latitudes 45° and 60° the temperature of the sea was lower than that of the air, the mean difference being 1°.4. The temperature of the air is here higher owing to the prevailing W.N.W. winds, and that of the sea lower owing to the numerous icebergs. To south of lat. 60° S. the sea was nearly 2°.0 warmer than the air, the result in this case being due to the open sea, which keeps up a higher surface temperature, and to an increased prevalence in these higher latitudes of southerly winds, thus lowering the temperature of the air.

The period during which the temperature of the sea exceeded that of the air was from June 1874 to March 1875, or during that part of the cruise from Sydney to New Zealand, and through the East India Islands to Hong Kong and thence to the Admiralty Islands. During the whole of this time, except when passing the north of Australia, the sea was much warmer than the air, the general excess being from 2° to 3°, rising even near Tongatabu to upwards of 4° The climate of the southern part of this extensive region at the seasons visited has a large rainfall, much cloud, and consequently a comparatively small evaporation and sunshine In June, when the "Challenger passed the north of Australia, the climate was very dry, the sunshine strong, and the evaporation large, and there the sea was slightly colder than the air In the Atlantic between lat 20° N and 20° S the sea was everywhere warmer, the mean excess being about a degree, and in the Pacific between lat 30° N and 30° S the sea was also warmer, the mean excess being a degree and a half

On the other hand, in the Atlantic from lat 40° to 20° N the sea was, on the mean, half a degree colder than the air This region is remarkable for the high pressure which overspreads it for the winds and currents which flow out in all directions for its clear skies, strong sunshine, and consequently large evaporation, by which the temperature of the surface of the sea is lowered and that of the air resting on it, being open to the heating influence of the sun, is raised Similarly in the North Pacific from lat 40° to 30° the temperature of the surface of the sea was half a degree lower than that of the air

These remarks apply only to the observations made strictly on the open sea Near land very great differences were observed which varied with season Thus at Hong Kong during the latter half of November 1874 the sea was 3° 7 warmer than the air the low temperature of the air at this season being caused by the lower temperature of the land and the northerly winds which then prevail, on the other hand, at Valparaiso in November and December of the following year the sea was 5° 8 colder than the air during the three weeks the "Challenger was there, the difference being due to the cold oceanic current which sweeps northwards past that coast, and the rapid increase in the temperature of the air at that time of the year These results will help us in gaining some knowledge of the temperature of the air over the oceans of the globe in February and August, taken in connexion with a careful examination of the sea temperature of these months represented in figs 8 and 9

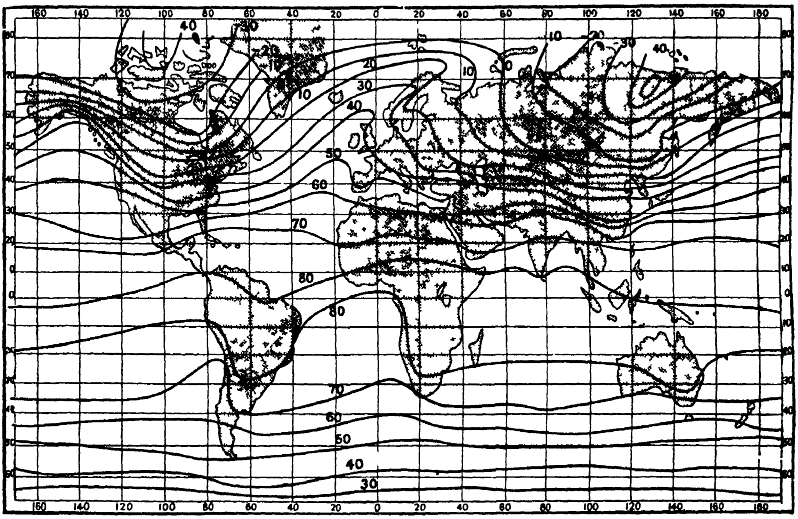


FIG 10 —January Isothermals of the Surface of the Globe

The distribution of temperature over the surface of the globe is shown by figs 10 and 11, which represent the temperature of the two extreme months January and July for the eleven years 1870 to 1880 The region of highest temperature, which may be regarded as comprised between the north and south isothermals of 80°, forms an irregularly shaped zone, lying in tropical and partly in subtropical countries On each side of this warm zone the temperature diminishes towards the poles, and the lines showing successively the gradual lowering of the temperature are, roughly speaking, arranged parallel to the equator, thus showing in an unmistakable manner the predominating influence of the sun as the source of terrestrial heat While this decrease of temperature corresponds in a general way to what may be called the solar climate, there are great deviations brought about by disturbing causes

Among these disturbing causes the unequal distribution of land and water holds a prominent place In January the earth presents to the perpendicular rays of the sun the most uniform surface, or the largest water surface, and in July the most diversified surface, or the greatest extent of land Hence the zone of the earth's surface comprised between the isothermals of 80° is less irregular, and also spreads over an area more restricted, in January than in July In July the areas enclosed by the isothermals of 80° and 90° are much larger in the Old World than in the New, it being the former which presents the larger land surface to the perpendicular rays of the sun, and in January, the summer of the southern hemisphere, the most extensive area of high temperature occurs in Africa and the least in Australia, the high temperature area of South America being intermediate In contrast to this the belt of temperature exceeding 80° is of least breadth where it crosses the Pacific and Atlantic Oceans, the absolute minimum breadth being in July in the Pacific, the largest ocean, where the disturbing influence of the land is least

During the cold months of the year, when the sun s heat is least and the effects of terrestrial radiation attain the maximum, the greatest cold is over the largest land surfaces which slant most to the sun Thus the lowest mean temperature that occurs anywhere or at any season on the globe is −55° 8 at Werchojansk (lat 67° 34 N, long 133° 51′ E) in north eastern Siberia In Arctic America the lowest isothermal is −40° 0 During the winter the ocean everywhere maintains a higher temperature in all regions open to its influence, as is seen, not only in the higher latitudes to which the isothermals push their way as they cross the Atlantic and Pacific, but also in their irregular courses over and near the Mediterranean, Black, Caspian, and Baltic Seas, Hudson s Bay the mouth of the St Lawrence, the American lakes, and all other large sheets of salt and fresh water The disturbing influence of sheets of water on the temperature in all seasons is very strikingly shown when the isothermals are drawn for every degree, these marking out the prominent features of local climates, a knowledge of which is of so great importance to the agriculturist, the horticulturist, and the invalid Figs 12 and 13 represent charts of temperature of this description for the British Islands for 1870–1880 from the *Jour of Scot Meteor. Soc*, vol. vi In the winter of the southern hemisphere the depressing influence of the land on the temperature is but slightly felt, owing to the small extent of the land surfaces and the comparatively low latitudes to which they extend southwards In the south east of Australia and in the basin of the La Plata, a lower temperature prevails in the interior

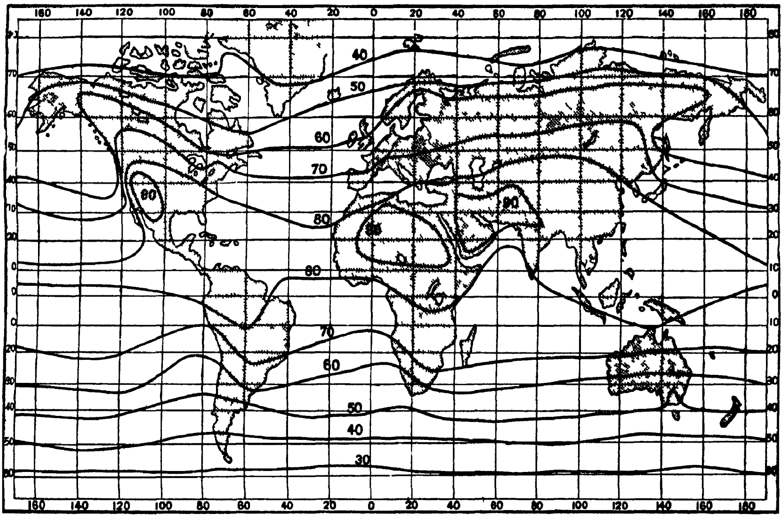


Fig 11 —July Isothermals of the Surface of the Globe

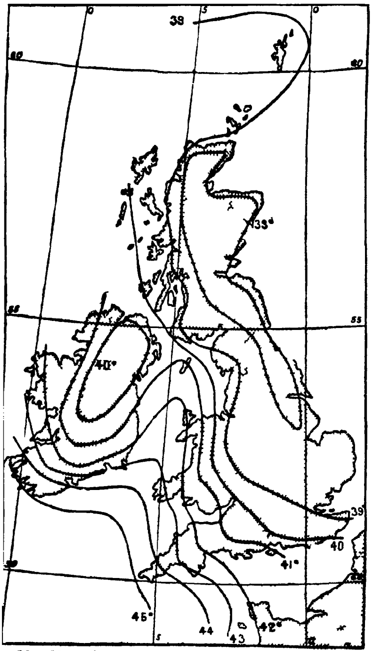


Fig 12 —Mean Temperature of the British Islands in January

Another prominent disturbing cause operating on the mean temperature is to be found in the seasonal areas of low and high mean pressure in their connexion with the prevailing winds Of these the most marked is the system of

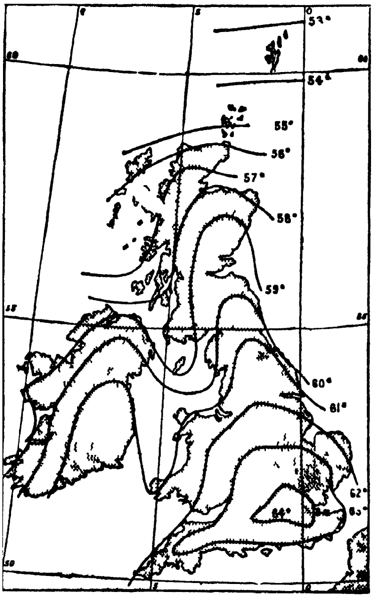


Fig 13 —Mean Temperature of the British Islands in July

low pressure about Iceland during the winter months (see fig 14). Since this region of low pressure gives to western Europe its prevailing south-west and south winds, and to North America its north-west winds in winter, it is plain that the temperature of western Europe is thereby abnormally raised by the simple fact of its prevailing winds coming from the ocean and from lower latitudes, and that the temperature of North America is abnormally lowered by its prevailing winds coming from the Arctic regions and from land. The opposite action of these two winds, which are part and parcel of the same atmospheric disturbance about Iceland, is shown from the fact that while the mean temperature of the south coast of Hudson's Bay in January is −20°, in the same latitude in the Atlantic to the west of Scotland it is as high as 44°, or 64° higher. A similar though less striking result accompanies the low pressure area in the north of the Pacific in winter.

Another area of low mean pressure which powerfully affects the temperature is the low barometer which overspreads the interior of Asia during the summer months (see fig 17). Since from this disposition of the pressure the prevailing winds of Europe and western Asia are north-west and west, and over eastern Asia south-east and east, it follows that the temperature is abnormally raised on the eastern side and depressed on the western side of the continent by the direction from which they severally receive their prevailing winds. This is well shown by the course of the summer isothermals of 80°, 70°, 60°, and 50° across the Old Continent.

Since the strongest insolation occurs where the sun is direct, the hottest summer climates are met with in those tropical and subtropical regions where no rain falls. The most extensive of the rainless regions during the summer months is perhaps that which extends from the Punjab westwards through Persia, Arabia, and North Africa to Spain. This is the region where the hottest climates of the globe are to be encountered. Similarly no rain falls at this time of the year in lower California and the States adjoining, and this feature of the climate, taken in connexion with the relatively low temperature of the coast due to the winds and ocean currents from the north which sweep past it, results in sharp contrasts of temperature within short distances such as have no parallel in any other climate.

Of the areas of seasonal high mean pressure, the high barometer of Central Asia in winter stands out in characteristic prominence (see fig 14). Now, since the prevailing winds which necessarily form a part of this feature are south and south-west over Russia and western Siberia, the temperature of these inland regions is considerably higher than would otherwise be the case. On the other hand, since the prevailing winds are north-west in eastern Asia, the temperature of these regions is thereby abnormally depressed. It is this consideration chiefly which explains how it is that, while the mean January temperature in latitude 60° and longitude 120° E. is −30°, in the same latitude but in longitude 43° E. the mean temperature is 10°, or 40° higher, even though both regions are equally continental in their character.

The high mean pressure in the summer in the Atlantic between Africa and the United States has with its system of winds the most decided influence in bringing about the abnormal distribution of the temperature of that and adjoining regions. Since on its west side the prevailing winds are necessarily southerly, the temperature of that region is abnormally raised, and, on the other hand, since on its east side the winds are northerly, the temperature of the region is abnormally depressed. The result of these two opposite winds is seen in the slanting direction of the isothermal of 80° across the Atlantic, which slanting direction is continued far into the interior of North America for the reasons already stated.

These important bearings of cyclonic and anticyclonic areas on temperature and climate may be thus summarized. The temperature is abnormally raised on the east sides of cyclonic areas, and abnormally depressed on the west sides, but, on the other hand, temperature is abnormally raised on the west sides of anticyclonic areas and depressed on their east sides. In the southern hemisphere these directions are reversed.

Another set of influences, powerfully affecting the temperature, come into play where the surface of the land rises above the sea into elevated plateaus, lofty peaks, or mountain ranges. Thus it has been observed on Ben Nevis and other mountains that the wind during the day in summer exhibits an ascensional tendency due to the circumstance that the temperature of the surface of the mountain is heated in a much greater degree than the air strata at the same levels all around it. An ascensional current consequently rises from the mountain, which is maintained at a steadily stronger rate than at lower levels, because the drain from the updraught is easily supplied from the free surrounding atmosphere. It is the strong insolation at high elevations in the summer months which explains the excessively high day temperatures encountered in the Rocky Mountains; and from the same conditions, viz., the rarity and purity of the atmosphere by which terrestrial radiation is but little checked, come the low temperatures of the nights of these climates in the same season. From this cause it follows that the elevated lands in the interior of continents tend to reduce mean atmospheric pressure in summer to a greater extent than would otherwise be the case. In winter, on the other hand, the temperature of elevated regions in the interior of continents is very much colder than that of the surrounding atmosphere at the same height, because in such regions the air is exceedingly dry and rare, and consequently radiation to the cold regions of space but little checked. Hence down the slopes of these high lands there are poured in all directions descending currents of very cold air, which intensify the rigours of the winters experienced on the low lands round their base, where accordingly the lowest mean winter temperatures occur. These elevated lands thus materially add to the high atmospheric pressure of the interior of continents during the cold months of the year.

But it is ocean streams and ocean currents which produce the greatest abnormalities in the distribution of the temperature of the air, and a glance at fig 10 and 11 will show that it is in the North Atlantic where this cause is most strikingly seen. The increase thus accruing to the winter temperature is greatest about the north of Norway. It is also very great in the British Islands; thus, if no more heat were received than is due to their position on the globe in respect of latitude, the mean winter temperature of Shetland would be 3° and that of London 17°. But mainly owing to the heat given out by the Gulf Stream and other warm currents of the Atlantic their mean winter temperatures are respectively about 39°·5 and 39°, Shetland being thus benefited 36°·5 and London 22°. The chart of the winter temperature of the British Islands well illustrates the influence of the surrounding ocean in maintaining a higher temperature. It will be seen that the south-west of Ireland is 7° warmer than the east coast of England in the same latitudes. The strong drift current from near Behring's Strait southward along the coast of America has a powerful influence, particularly in lowering the summer temperature of that coast,—thus bringing about, in conjunction with the dry rainless climate of the interior, what are perhaps the most violently contrasted climates, within narrow limits, as regards their temperature The deflexions of the isothermals near the Baltic, Mediterranean, Black, and Caspian Seas and the freshwater lakes of America all point to the disturbing influence of these sheets of water on the temperature

The height and direction of mountain ranges is an important element in determining climate If the ranges are perpendicular to the prevailing winds and of a considerable height, they drain the winds of much of their moisture, thus causing to places to leeward colder winters and hotter summers, by partially removing their protecting screen of vapour, and exposing them more completely to solar and terrestrial radiation Of this Norway and Sweden and the British Islands form excellent illustrations It is this that makes the most important distinctions among climates in regions near each other, as respects both animal and vegetable life With regard to the decrease of temperature with height, very much yet remains to be done before an approximation to the law of decrease can be stated During the five months observations were made on Ben Nevis in the summer of 1881 the difference between the mean temperature at sea level adjoining and at the top of the Ben, 4406 feet above the sea, was 15° 7, which shows a mean decrease of 1° Fahr for every 280 feet of elevation The actual differences from day to day varied from 1 4 to 23° 2 As Ben Nevis forms a peak, and is in the very middle of the strong winds from the Atlantic it is highly probable that this rate of decrease is a close approximation to the true decrease of the temperature of the air during the summer months in that part of the British Islands When observations are made on elevated plateaus of some extent, the rate of decrease deduced from the observations will be less than the true rate in the free atmosphere in summer and greater in winter The rate is thus a variable quantity, varying with latitude, situation, dampness or dryness of the air, calm or windy weather, and particularly with the season of the year One degree Fahrenheit for every 300 is the rate of decrease generally assumed

Amount of Aqueous Vapour —It is scarcely possible to overestimate the importance of a knowledge of the horizontal and vertical distribution in the atmosphere of its aqueous vapour, for it may be truly said that it forms one of the prime factors in all the larger problems of atmospheric physics A first rough approximation to the geographical distribution of the vapour of the atmosphere was published by Mohn in 1875 in his *Grundzuge der Meteorologie*, p 84, in which vapour pressure curves are drawn for the globe for January and July These leave much still to be done, not only in a further discussion of observations already made, but also in improvement of the methods of observation and in the tables for their reduction The chief point of interest in Mohn s vapour curves their striking resemblance to the isothermals of the same months, and they also suggest that this line of inquiry is yet destined to make large contributions to our knowledge of the unceasing changes which occur in the pressure temperature, cloud, rain, and movements of the atmosphere

Still less is known of the vertical distribution of aqueous vapour It decreases like temperature, with the height,

only about a tenth of what is at the earth s surface the rate of decrease with height proceeds at a greatly more rapid rate than is consistent with the supposition that it forms an independent vapour atmosphere existing under its own pressure The establishment of an increased number of high level stations, and a more systematic inquiry than has yet been attempted into the upper currents of the atmosphere, are much needed in the further development of this branch of meteorology In carrying out the inquiry, invaluable assistance will be obtained from observations of the diurnal range of the barometer and from well devised methods of observing the effects of solar radiation at the earth s surface

Amount of Cloud —In Scotland, which lies completely within the region swept by the south westerly winds from the Atlantic, and presents a well defined mountain range lying across the track of these winds, the clouds have a distinct annual period In the west, at places quite open to these westerly breezes, the amounts of cloud in spring, summer, autumn, and winter are respectively 67, 69, 71, and 74, and the annual mean 70[1] In the east, in such districts as East and Mid Lothian, which have extensive ranges of hills between them and the Atlantic, the proportions are 59, 63, 62, and 60, and the annual mean 61 Thus about a tenth more of the sky is covered with cloud at the western as compared with the eastern situations, and the distribution of cloud differs materially in western and eastern climates In the west winter is the cloudiest season, but in the east it is summer, and these are respectively the months when most rain falls in the several climates Everywhere spring is the season when the sky is clearest In England, owing to the protection afforded by Ireland and Wales to the west and the comparative absence of ranges of hills, the amount of cloud is less than in Scotland, and it is more equally distributed over the country The minimum amount occurs in spring, and the maximum in winter and autumn

Some of the best illustrations of the seasonal variation in the distribution of cloud are afforded by the Old Continent These variations are the simple consequence of the systems of wind caused by the high winter and low summer pressures of that continent In eastern Siberia the prevailing winds in winter are N W or continental and in summer S E or oceanic and accordingly at Ajan Nertchinsk and Blagoweshtchensk the mean amounts of cloud in these two seasons are 18 and 44 On the other hand in western Siberia and eastern Europe the prevailing winds in winter are S W or from lower to higher latitudes and in summer N W or from higher to lower latitudes Kazan may be taken as fairly representing this extensive region and there the amounts of cloud for the four seasons beginning with winter are 71 48 44 and 62 As the N W winds of summer rise over the Ural mountains in their course condensation of the aqueous vapour is increased and hence over this region the cloud in winter and summer is nearly the same the mean amounts at Bogoslovsk Ekaterinburg and Zlatoust being respectively 53 and 52 At Tiflis and Kutais situated on the high ground which lies between the Black Sea and the south of the Caspian Sea the means for winter and summer are 53 and 55 On the eastern coast of the Black Sea the westerly winds of summer are accompanied with the annual maximum cloud, the winter and summer amounts at Redut Kale being 59 and 69 In Central Siberia to which the S W winds of winter do not extend, and to the north of latitude 55°, the amount of cloud is much diminished and the cloudiness of summer is nearly the same as that of winter

In India in all regions which lie open to the summer monsoon the minimum amount of cloud occurs during the winter and the maximum in summer,—the mean amounts being 19 and 74 at Calcutta, 16 and 86 at Bombay, 48 and 71 at Colombo and 25 and 90 at Rangoon At Trincomalee on the east coast of Ceylon, and thus exposed to the rains of the N E monsoon of winter, and largely protected from the rains of the S W monsoon of summer the amounts of cloud in these seasons are 52 and 59 At Darjiling (6912 feet) and Chakrata (7022 feet high) both on the Himalayas, whither the summer monsoon penetrates,

southern Asia to which the summer monsoon does not extend the cloud in winter is everywhere greater than in summer Thus the amounts are 24 and 18 at Mooltan, 38 and 25 at Peshawar, 27 and 19 at Jacobabad, and at Quetta in Baluchistan 5500 feet high, 42 and 14 Similar relations as to cloud obtain in Australia and the other continents where high pressures rule in the interior during the cold months and low pressures during the warm months of the year. The maximum cloud occurs with winds from the sea and winds advancing into the colder regions of higher latitudes, and the minimum with winds which have traversed an extensive track of land and winds advancing into the warmer regions of lower latitudes. As the subject, however, is essentially one with rainfall, it is not necessary to prosecute it further.

---

[1] In this section the amount of cloud is stated in percentages of the sky covered with cloud

The other atmospheric movements on which the amount of cloud depends are the ascending and descending currents of the atmosphere,—the ascending currents with clouded skies occurring in the belt of calms and over cyclonic areas and regions, and the descending currents with comparatively clear skies over anticyclonic regions. The region of maximum vapour and densest cloud screen on the globe is the equatorial belt of calms between the trades, which has an annual movement northward and southward with the sun as already explained. To ascensional movements is to be ascribed part of the cloudiness of the southern and eastern sides of the winter cyclonic regions of the North Atlantic and North Pacific, and of the cyclonic regions of low summer pressure in the interior of Asia and other continents. On the other hand the comparatively small amount of cloud in the anticyclonic regions of the Atlantic and Pacific Oceans, and in the high pressure regions of the interior of Asia and other continents during the cold months of the year, is due to the vast down currents which occupy the centres of the anticyclones, and which become relatively drier as they descend owing to the increasing pressure to which the air is subjected.

Distribution of Atmospheric Pressure.—The importance of a knowledge of the distribution of atmospheric pressure, or of the mass of the atmosphere, over the globe in its varying amounts from month to month is self-evident. Observations teach us that winds are simply the movements of the atmosphere that set in from where there is a surplus towards where there is a deficiency of air; and observations also teach that isobaric maps (*i.e.*, maps showing the relative distribution of mean pressure) and maps showing the prevailing winds are in accordance with each other. Since prevailing winds to a large extent determine the temperature and rainfall of the regions they traverse, isobaric maps may be considered as furnishing the key to the more important questions of meteorological inquiry. At the time of the first publication of isobaric maps of the globe in 1868, it was impossible to do more than present the subject in its broad general features, owing to the scantiness and quality of the materials then existing. But since then meteorological stations have been largely multiplied in all parts of the civilized world, and the general adoption of the issue of storm warnings has necessitated the use of more accurate barometers and uniform methods of observing. Since there is thus now the means of a more exact representation of this fundamental datum of meteorology, we have prepared a new set of isobaric maps, showing the distribution of the earth's atmosphere and the prevailing winds for January (fig. 14), July (fig. 17) and the year. They have been constructed from mean values calculated for the same eleven years (1870-80 inclusive) as the isothermal maps figs. 10 to 13, pressure of 30.0 inches and upwards being represented by solid lines, and of 29.9 inches and under by dotted lines, while the arrows show the directions of the prevailing winds at the localities indicated by the respective arrow-points.

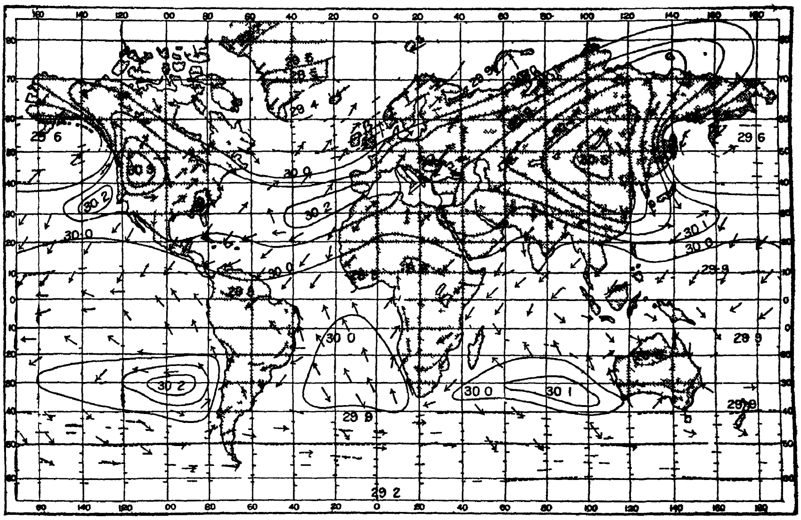


FIG. 14.—January Isobars of the Globe and Prevailing Winds.

Mean Atmospheric Pressure in January (fig. 14).—In this month, when the influence of the sun on the northern hemisphere falls to the minimum, the greatest pressures are massed over the continents of that hemisphere, and the least pressures over the northern parts of the Atlantic and Pacific Oceans, over the Antarctic Ocean and southern hemisphere generally. In the southern hemisphere there are three patches where pressure rises to 30 inches, viz., in the Atlantic between South America and Africa, south of the Indian Ocean, and in the Pacific between Australia and South America.

In the northern hemisphere, on the other hand, pressure rises in Central Asia to upwards of 30.5 inches, the mean pressure for January being at least 30.4 inches at Peking, Semipalatinsk, and Yenisei, and fully 30.5 inches at Irkutsk and Nertchinsk in the upper basin of the Amur. This is the region where the normal atmospheric pressure attains to a maximum which is much higher than is reached in any other region or at any other time of the year. It will be observed that this region of highest pressure occupies a position near the centre of the largest continent. The area of high barometer is continued westward through Europe, through the horse latitudes of the Atlantic to Carolina, and thence through the United States to California, whence it crosses the Pacific to Asia. This belt of high pressure thus completely encircles the globe, broadening as it passes the land and contracting as it crosses the ocean. Its greatest breadth is over Asia and its least over the Pacific, or where land and ocean attain respectively their maximum dimensions.

Pressures greatly under the average cover the northern portions of the Pacific and Atlantic and also the greater part of the Arctic regions. In the north of the Pacific the normal pressure falls to about 29.6 inches between Kamchatka and Alaska. In the north of the Atlantic, however, a still lower mean pressure obtains over a narrow belt stretching from Iceland to the south of Greenland, the normal at Stykkisholm in the north west of Iceland being 29.385 inches, and at Ivigtut in Greenland 29.361 inches. This low average for Ivigtut is the lowest normal known to occur anywhere and at any season in the northern hemisphere, and it is significant that the place is immediately to the north of that part of the Atlantic where a considerable number of the storms which sweep over Europe have their origin, and where not a few of the storms which cross the Atlantic from America develop intensity.

It has been seen that the highest mean pressure occurs near the centre of the largest extent of land, but as regards the two oceans the lowest pressure is met with in the northern division of the Atlantic, which is the lesser ocean. An inspection of fig. 14 shows, however, that the low pressure area of the Atlantic is bounded to southward by systems of much higher pressures than are to be found in the Pacific. The result of this arrangement is that much stronger winds blow northward over the Atlantic and round upon Iceland, and, as these more quickly advance into colder latitudes, there is thus a greater and more frequent condensation of vapour and lowering of the barometer in the north of the Atlantic. The heavy rainfall of north western Europe may be referred to as confirming this view.

[illegible] of l[illegible] pr[illegible] equ[illegible] quite round the globe. This marks the well known region towards which on either hand the trade winds blow. In the Atlantic it lies quite north of the equator even in January when the sun's course is farthest to southward, and it lies nearly parallel with the equator. On the other hand in the Indian Ocean the position of the line of lowest pressure is to the south of the equator and not parallel with it, but taking a slanting course from near the north of Madagascar towards Sumatra, then towards the low pressure which prevails at this season in Australia; its course is then a little to northwards and crosses the Pacific to the central regions of South America. Its path is thus a devious one, being north of the equator only in the eastern part of the Pacific and in the Atlantic, but elsewhere to the south of it, being drawn furthest southward when under the influence of the regions of low pressure which now occupy central Australia, central and southern Africa, and central South America. In this trough of barometric depression nearly all the tropical storms of the Indian Ocean have their origin.

There are several important modifications of the isobaric lines as originally published. In 1868 the region of lowest pressure in the northern hemisphere in winter was represented as extending from Iceland to north eastward; now the area of lowest pressure is seen to extend from Iceland south westward to Greenland. In connexion with this point Captain Hoffmeyer discussed the weather of the North Atlantic during several winter months and published the results in 1878, which conclusively showed that the meteorology of Greenland and Iceland exerts on the distribution of atmospheric pressure a powerful influence not before properly recognized, resulting in the mean minimum of pressure being localized distinctly to the south west of Iceland, and that in addition to this minimum there are two subordinate minima, one in Davis Straits and the other in the Arctic Ocean midway between Jan Mayen and the Lofoten Isles. The investigation further established the fact that when one particular one of these three minima plays an important part the other two either do not appear at all or occupy quite a subordinate place, and that according as one or other of these minima of pressure predominates so is the character of the weather, as regards mildness or severity of the winter of north western Europe and regions surrounding the North Atlantic. As regards the British Islands, the displacement of the minima to westward of the position shown in fig. 14 means milder winter weather, whereas a position more in the direction of the north of Norway means severer winter weather.

Another change implying important consequences is seen in the United States, where, instead of one, two distinct centres of maximum pressure occur, or rather the high pressure of the western and central States is separated from that of the south eastern States by a region of lower pressure occupying the region of the Mississippi States. Professor Loomis first drew attention to this peculiarity in 1879 in an inquiry into the distribution of pressure over the United States, and established the fact that there are two distinct areas of high pressure, the larger having its centre in Utah, and the less overspreading the greater portion of the south eastern and southern States, and that these two areas of high pressure are clearly separated from each other by a broad extensive region of lower pressure stretching in a south western direction from the region of the great lakes to western Texas. The reason assigned by Professor Loomis is undoubtedly correct, that the relatively low normal pressure of the Mississippi States is due to the fact that the path usually taken by the barometric minima of American storms in the earlier part of their course is from Texas to the lakes. Since, on the other hand, the centres of comparatively few storms, with their low barometer readings, cross the southern and south eastern States, the normal winter pressure is higher there than it is along the Mississippi.

Another important modification occurs in India, where the isobar of 30 inches is deflected to the south east toward Madras and thence towards the north east to near Akyab in Arakan. This remarkable deflexion well shows the important influence exerted on the course of the isobar by large well defined sheets of water and extensive tracts of land. The distribution of pressure here indicated, by which south of lat. 22° the normal pressure is considerably higher in the east than in the west of India, has, through the agency of the winds resulting from it, the most intimate and vital bearings on the distribution of the winter rains and temperature over considerable portions of India, and the same relations hold, but in a degree still more striking, in the meteorology of Ceylon.

The remarkable effect in interrupting or changing the course of the isobars is particularly well illustrated by the lines in the region of the Aral, Caspian and Black Seas. As the point is of no small importance in meteorology, and is best illustrated by the Mediterranean and the countries to the north of it, we subjoin a map of this part of Europe (fig. 15), showing the normal pressure with greater distinctness and fulness than could be shown on fig. 14, the isobars being drawn for every half tenth of an inch.

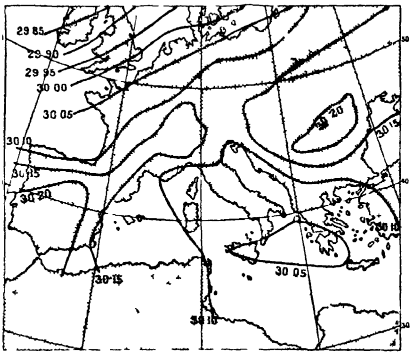


FIG. 15.—Isobars of Jan.

Here we see two distinct areas of high pressure, the one in Hungary and the other in the Peninsula, where the normal pressure exceeds 30.20 inches. The latter is the larger of the two, and may be regarded as the prolongation of the region of high pressure which characterizes the Atlantic immediately to the south west at this season. The high pressure area included within the isobar 30.15 inches is of peculiar interest. In the Peninsula it covers a pretty broad area, but to the north east it contracts to a narrow neck between the Bay of Biscay and the Gulf of Lyons, and again expands to north eastward covering the distance from Carlsruhe to Modena, its prolongation eastward being there somewhat suddenly interrupted. At some distance to the eastward the second region of high pressure is met with, which is properly a part of the high pressure that overspreads the interior of the Old Continent in the winter months, its western limit being the isobar of 30.15 inches, which passes round by Pinsk, Cracow, Vienna, Laibach and the upper southern slopes of the basin of the Danube, Sebastopol, and thence southward in the direction of Cyprus.

The position of the latter of these regions of high pressure is approximately midway between the south coasts of Asia Minor and the Baltic. In other words, its position occupies the interior of this part of the Old Continent, and it is instructive to note that the position of the Black Sea and the Greek archipelago in the south portion of this region pushes the isobar of 30.15 inches a good deal to northward. The position of the region of high pressure in the Peninsula, France, and Switzerland is also decidedly inland. It does not, however, exactly occupy the middle space of the land lying between the Mediterranean and the North Sea, owing no doubt to the circumstance that the very steep barometric gradient from France to Iceland greatly lowers the pressure over the whole of the northern half of France. It follows that the abnormally high pressure which so remarkably characterizes the interior of the Old Continent during the cold months of winter is represented, though in a greatly reduced form, westwards through the central districts of that continent.

These two regions of high pressure are separated from each other by a large area of comparatively low pressure overspreading the greater portion of the Mediterranean Sea—marked off in fig. 15 by the isobar of 30.10 inches, within which pressure is everywhere less than 30.10 inches. This region includes an area of still lower pressure within the isobar of 30.05 inches, bounded by Sicily, Corfu, Athens, and Crete. Hence the singularly low pressure which characterizes the northern part of the Atlantic at this season has its analogue in the south of Europe, which is unquestionably due to the higher temperature and larger humidity of the climates of southern Europe, which they owe to the Mediterranean.

It is deserving of special notice that, while the increase of the normal pressure of January from Genoa to Geneva is 0.081 inch, it is only 0.021 inch from Trieste to Riva; and that to the north of the Adriatic as far as latitude 50° pressure is considerably lower than obtains to the west and east of that region. An examination of the daily weather maps of Europe shows that not unfrequently the storms of north-western Europe, on advancing as far to eastward as Denmark, seem to connect themselves in some degree with Mediterranean storms prevailing at the time through a north and south prolongation of a system of low pressures. The comparative frequency with which this occurs is probably occasioned by the general drift to eastward of the atmosphere of Europe, considered as a whole, taken in connexion with the high mountainous ridge which bounds the Adriatic on its eastern side; from which it follows that the air overspreading the deep basin of the Adriatic is often highly saturated with vapour, and this highly saturated air is drawn northwards through central Europe when north-west storms of Europe with low barometric depression centres pass across Denmark and the Baltic. Thus the low normal pressure to the north of the Adriatic, separating the two regions of high pressure to the east and west of it, is in some respects analogous to the low normal pressure of the Mississippi valley, which separates the higher normal pressures of the Rocky Mountains and of the south-eastern of the United States.

The influence of land and water respectively in the cold season of the year is well shown in fig. 16, which represents for every 0.02 inch the normal pressure over the British Islands in January, drawn from means calculated for two hundred and ninety-five stations.[1]

It is in the winter months that the isobars of the British Islands crowd most closely together, and in accordance therewith strong winds are then most prevalent. The crowding of the isobars reaches the maximum in January, forming what is probably the steepest mean monthly barometric gradient that occurs at any season anywhere on the globe. The point, however, to which attention is here drawn is the remarkable influence of St George's Channel and the Irish Sea in diminishing the pressures as the isobars cross these seas, and of the land in increasing the pressure, which is seen in the curves occupying approximately the central districts of Great Britain from the Isle of Wight to Cape Wrath. This shows on a comparatively small scale the influence of the land in raising the normal pressure and of the sea in lowering it, during the cold months of the year, just as is seen on the grand scale in central Siberia and the north of the Atlantic.

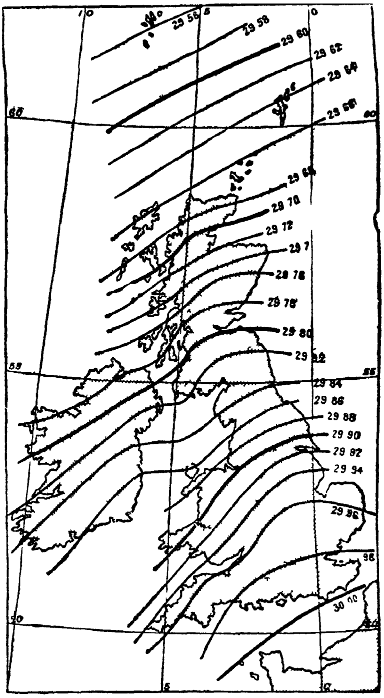


FIG. 16.—Isobars of the British Islands for January.

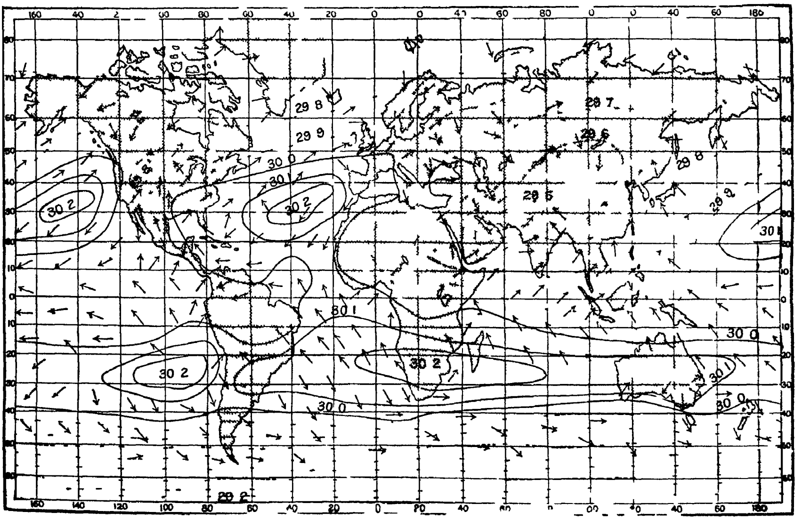


FIG. 17.—July Isobars of the Globe and Prevailing Winds.

Mean Atmospheric Pressure in July (fig. 17).—In this month the physical conditions are the reverse of what obtains in January, the effects of the influence of the sun on the temperature and humidity of the atmosphere rising to the maximum in the northern and falling to the minimum in the southern hemisphere. With the solar conditions reversed, a comparison of figs. 14 and 17 shows that the distribution of atmospheric pressure in July is, considered in a broad sense, the reverse of what takes place in January.

---

[1] See *Journal of Scot. Meteorological Society*, vol. vi. pp. 4–21.

In the southern hemisphere atmospheric pressure during the winter season is above the general average of 30 inches between lat. 10° and 40° S. This belt of high pressure encircles the globe and embraces four regions where pressure rises considerably above this general high average. These regions are in South Africa, about lat. 20°, where it rises to a little above 30·20 inches; in Australia, where it rises on the Murray river very nearly to 30·20 inches; in South America, where in the basin of the La Plata, about lat. 30°, it rises to 30·13 inches; and in the ocean to westwards, where it reaches 30·02 inches. The point to be noted with respect to the position of these centres of high pressure at this season is that they occur over surfaces between latitudes 20° and 30°. As compared with January, pressure in July over nearly the whole of this broad belt of the southern hemisphere is about two-tenths of an inch higher, which is the simple result of season. A comparison of January and July shows that this large accession to the pressure of the southern hemisphere is accompanied by an extraordinary diminution of pressure over the continents of the northern hemisphere.

Now, just as the greatest excess of pressure during the winter of the northern hemisphere occurs in the continent of Asia, so the greatest diminution of pressure in the summer months takes place in the same continent. The position, however, of the two extremes is far from being in the same region or even near each other. In the Old Continent the maximum occurs in the valley of the upper Amur, where at Nertchinsk the normal pressure in January is about 30·600 inches, whereas the lowest normal pressure in July is 29·412 inches, and occurs, so far as observation enables us to locate it, at Jacobabad, on the west side of the basin of the Indus. The difference of these two normals is 1·188 inch, and over no inconsiderable portion of central Asia the normal pressure of July is an inch less than that of January. In other words, the influence of the sun in summer as exerted on the temperature and aqueous vapour of the atmosphere, and atmospheric movements resulting therefrom, is so powerful as to remove a thirtieth part of the whole mass of the air from this extensive region.

The large extension in recent years of good meteorological stations over the Russian and Indian empires enables us to lay down with much greater precision than formerly the lines of pressure. Of the changes indicated by the new isobars the most important perhaps is the position of the region of minimum pressure in Asia, which is now seen to occupy the basin of the Indus, and thence stretches over a somewhat broad region to westward nearly as far as the head of the Persian Gulf. The point is of no small importance in atmospheric physics, inasmuch as it places the region of least normal pressure in July as close geographically to the region where at the time terrestrial temperature is highest as the region of highest normal pressure in January is situated with respect to the region where in that month terrestrial temperature is lowest in Asia.

The July isobars of India are of singular interest, and imply consequences of the utmost practical advantage to the empire. From Cutch southward the normal pressure is everywhere higher, and considerably so, along the whole of the west than it is in the east in the same latitudes, the difference being approximately half a tenth of an inch. This is represented on the map by the slanting of the isobars from north-west to south-east as they cross this part of India; and it is to be noted that the east and west coasts of Ceylon show the same manner of distribution of the pressure. The consequence of this peculiarity in the distribution of the pressure is that the summer monsoon blows more directly from the ocean over western and southern India than would have been the case if the isobars had lain due east and west, and thus probably precipitates in its course a more abundant rainfall over this part of the empire. But a more important consequence follows from the geographical distribution of the pressure over the valley of the Ganges. If the normal pressure there had diminished in the manner it does over India to the south of the Gangetic valley, the winds would have been south-westerly and the summer climate practically rainless. This, however, is not the case, but the normal pressure diminishes westwards along the valley of the Ganges, as the following mean July pressures will show:—Calcutta, 29·576 inches; Patna, 29·535 inches; Lucknow, [illegible] inches; Roorkee, 29·505 inches; and on crossing westward into the Punjab pressure falls still lower—to 29·439 inches at Mooltan and 29·412 inches at Jacobabad. Indeed pressure in July is 0·220 inch lower at Jacobabad than at Sibsagar on the Brahmaputra, nearly in the same latitude. It necessarily follows from this distribution of the pressure that the summer monsoon, which blows northward over the Bay of Bengal, is deflected into an E.S.E. wind which fills the whole valley of the Ganges, distributing on its way a most generous rainfall over that magnificent region.

The influence of the land in lowering the pressure in summer is well illustrated by the course of the isobars over western Siberia and Russia, where pressure is seen to fall relatively lowest along the middle line of the Old Continent. In this connexion it is interesting to note the course of the isobar of 29·90 inches over that part of Europe where the breadth of the land is considerably increased—between the Baltic and Constantinople. In contradistinction to this the influence of the Aral, Caspian, and Black Seas in maintaining a higher pressure appears in the remarkable prolongation eastward of the isobars of higher pressure over the region of these seas, being in striking contrast to the lower pressures which prevail to the north and south.

The lowering of the normal pressure is very decided in the inland regions of Spain, North Italy, and Scandinavia. The effect is most strongly seen in Spain, the largest and compactest of these regions. Thus, while the normal pressure diminishes between Lisbon and Barcelona from 30·086 to 30·048 inches, the sea-level pressure at Madrid falls nearly to 30·000, and the pressure at Saragossa and Valladolid is nearly as low. This lowering of the pressure over the interior influences materially its summer climate. As remarkable an illustration of the principle as can be pointed to anywhere is seen in the north of Italy; for, while the normal pressure at Moncalieri is 29·941 inches, at Genoa on the coast the relatively high normal of 29·992 inches is maintained, the distance of the two places being about 40 miles. To the east pressure rises to 29·970 inches at Venice and to westward to 30·023 inches at Geneva. Over Scandinavia along the west coast from the Arctic circle southward, the normal pressure equals or exceeds 29·80 inches, the variation being comparatively small; and along the coast from the head of the Gulf of Bothnia to the south-east of Sweden pressure also exceeds 29·80 inches, and the increase from north to south proceeds at a slow rate. In, however, the strictly inland districts to the north-east of Christiania, which lie immediately to the east of the Scandinavian mountains and sheltered by that lofty range from the winds of the Atlantic, pressure is considerably lower than it is along the east and west coasts of the peninsula. Owing to this peculiar distribution of the pressure the winds which necessarily result from it give a much finer summer climate to the south-east of Norway and to the strictly inland part of Sweden than would otherwise be the case.

The remarkable curving northward of the isobar of 29·80 inches so as to include Lapland within it points probably to the influence of the White Sea and the wonderful lake system of Lapland in maintaining a higher summer pressure over that country, by which the northerly winds that blow towards the low-pressure region of Central Asia, to the serious deterioration of the summer climate of northern Siberia, do not extend so far to westward as Lapland.

The distribution of the normal pressure over North America is quite analogous to what prevails over Asia; but, the continent being less, the diminution of pressure in the interior is also correspondingly less. The highest normal pressure, 30·077 inches, is found in the south-east in Florida, and the lowest, 29·780 inches, in Utah, the difference being thus 0·297 inch. Another region of relatively high pressure is in the north-western States and British Columbia to the north; the maximum, near the mouth of the Columbia river, reaches 30·062 inches, being thus nearly as high as what occurs in Florida. These two regions are merely extensions of important high-pressure areas which at this season are highly characteristic features of the meteorology of the North Pacific and North Atlantic respectively.

Of these two regions of high pressure the one overspreading the Atlantic between the United States and Africa is the more striking, being not only the region where pressure is highest anywhere on the globe during the months of June, July, and August, but where the normal pressure reaches the highest point attained at any season over the ocean. The highest point reached by the normal pressure over the land at any season occurs, as has been pointed out, near the centre of Asia, or approximately in the middle region of the largest continuous land surface on the globe during the coldest months of the year. On the other hand, the highest pressure over the ocean occurs during the warmest months of the year, and not over the largest water surface, but in the middle regions of the North Atlantic, where the breadth is only about half that of the water surface of the North Pacific.

From the essential differences between these two sets of phenomena it may be inferred that the extraordinarily high pressure which is so marked a feature of the meteorology of Central Asia during the cold months of the year is a direct consequence of the lowering of the temperature of the land of Asia and of the atmosphere resting on it during the time of the year when the effects of solar radiation are at the annual minimum, and of terrestrial radiation at the annual maximum. But the determination of the place and time of highest pressure over the ocean must be regarded as indirectly brought about. The physical conditions under which it occurs are these:—it happens (1) at the time of the year when the earth presents the largest surface of land to the sun, and (2) over that part of the ocean which is most completely surrounded by these highly heated land surfaces. This high summer pressure of the Atlantic has its origin in the upper currents of the atmosphere.

Mean Atmospheric Pressure for the Year.—The distribution of the annual atmospheric pressure may be considered as representing the sums of the influences directly and indirectly at work throughout the year in increasing or diminishing the pressure of the atmosphere. There are two regions of high pressure, the one north and the other south of the equator, which pass completely round the globe as broad belts of high pressure. The belt of high pressure in the southern hemisphere lies nearly parallel to the equator and is of nearly uniform breadth throughout, but the belt north of the equator has a very irregular outline and shows great differences in its breadth and its inclination to the equator. These irregularities wholly depend on the peculiar distribution of land and water which obtains in the northern hemisphere.

These two zones of high pressure enclose between them the comparatively low pressure of the tropics, through the centre of which runs a narrower belt of still lower pressure, towards which the trade winds on either hand blow. Considered in a broad sense there are only three regions of low pressure, the equatorial one just referred to, and one round each pole bounded by or contained within the zones of high pressure just described. The most remarkable of these, so far as it is known, is the region of low pressure about the south pole, which remains low throughout the year, playing the principal role in the wind systems of the Antarctic zone, in its heavy snowfall and rainfall, and in the enormous icebergs which form so striking a feature of the water of the Southern Ocean.

the low pressure area round Iceland is the deeper, and is probably occasioned by the steeper barometric gradients and stronger winds which prevail over the North Atlantic. The broad equatorial zone of low pressure also contains two distinct regions characterized by still lower pressures. The larger of the two stretches across southern Asia from Assam to the head of the Persian Gulf, and is entirely due to the very low pressures which form so marked a feature in the summer meteorology of that part of Asia. The regions of the middle Indus and upper Ganges occupy the centre of this low pressure area, where normal pressure falls short of 29.80 inches. The second area of lowest equatorial pressure is in the centre of Africa.

It may be here pointed out that the whole of these areas of low mean annual pressure possess the common characteristic of an excessive amount of moisture in the atmosphere. The Arctic and Antarctic zones of low pressure and the equatorial low pressure zone generally may be regarded as all but wholly occasioned by the comparatively large amount of vapour in their atmosphere. As regards the region of low pressure of southern Asia in summer, it is remarkable that while the eastern half, which overspreads the valley of the Ganges, is characterized by a moist atmosphere and large rainfall, the western half of it is singularly dry and practically rainless, and that the central portion of this remarkable depression occupies a region where at the time the climate is one of the driest and hottest anywhere to be found on the globe. Hence, while the vapour is the more important of the disturbing influences at work in the atmosphere, the temperature also plays no inconspicuous part directly in destroying atmospheric equilibrium, from which result winds, storms, and many other atmospheric changes.

The Prevailing Winds of the Globe.—If atmospheric pressure were equal in all parts of the earth we should have the physical conditions of a stagnant atmosphere. Such, however, is not the case. Let there be produced a concentration of aqueous vapour over a particular region, or let one region show a higher temperature than what prevails around it, then from the different densities, and consequently different pressures thereby produced, the equilibrium of the atmosphere is destroyed, and, as might be expected from the laws of aerial fluids, movements of the air, or winds, set in to restore the equilibrium. Now every one of the isobaric maps we have given, as well as every isobaric map which has been made from recorded observations, indicates very considerable disturbance of the equilibrium at the surface of the earth. All observation shows that the prevailing winds of any region at any season of the year are simply the expression of the atmospheric movements which result from the disturbance of the equilibrium of the atmosphere indicated by the isobaric maps for that season and region.

All winds may be regarded as caused directly by differences of atmospheric pressure, just as the flow of rivers is caused by differences of level, the motion of the air and the motion of the water being both referable to gravitation. The wind blows from a region of higher towards a region of lower pressure,—in other words from where there is a surplus to where there is a deficiency of air, and this takes place whether the differences of pressure be measurable by the barometer, as is generally the case, or not readily measurable, as in the case of sea breezes, squalls, and sudden gusts of wind which are of short duration.

So far as is known, differences of atmospheric pressure, and consequently all winds, originate in changes occurring either in the temperature or the humidity of the air over restricted regions. Thus, if two regions contiguous to each other come to be of unequal temperature, the air of the warmer region, being specifically lighter, will ascend, and the heavier air of the colder region will flow in below to take its place. Of this class of winds the sea and land breezes are the best examples. Again, if the air of one region comes to be more highly charged with aqueous vapour than the air of surrounding regions, the air of the more humid region being lighter will ascend, while the heavier air of the drier regions will flow in below and take its place. Since part of the vapour will be condensed into cloud or rain as it ascends, heat is thereby disengaged, and the equilibrium still further disturbed. In this way originate gales, storms, tempests, hurricanes, and all the more violent commotions of the atmosphere, except some of the forms of the whirlwind, such as dust storms, in the production of which very great differences of temperature are more immediately and exclusively concerned.

The Trade Winds.—From fig. 14, giving the isobarics for January, it is seen that atmospheric pressure in the Atlantic is lower near the equator than it is to north and south of it, and the arrows indicate that to the north of the tract of lowest pressure N.E. winds prevail and to the south of it S.E. winds. These are the well known N.E. and S.E. trade winds, which thus blow from regions of high pressure towards the tract of lower pressure situated midway between them. The trade winds do not blow directly to where the lowest pressure is, but in a slanting direction at an angle of about half a degree. The deviation from the direct course is due to the influence of the rotation of the earth on its axis from west to east,—an influence to which all winds and all currents of the ocean are subject.

In virtue of this rotation, objects on the earth's surface at the equator are carried round towards the east at the rate of about 17 miles a minute. On receding from the equator, however, this rate of velocity is being continually diminished, so that at 60° N. lat. it is only about 8½ miles a minute, and at the poles nothing. From this it follows that a wind blowing along the earth's surface in the direction of the equator is constantly arriving at places which have a greater eastward velocity than itself. As the wind thus lags behind, these places come up as it were against it, the result being an east wind. Since, therefore, the wind north of the equator is under the influence of two forces—one, the low pressure near the equator, drawing it southwards, and the other, the rotation of the earth, deflecting it eastwards—it will, by the law of the composition of forces, take an intermediate direction, and blow from north-east. For the same reason, south of the equator the south is deflected into a south east wind.

In the Atlantic the north trades prevail between latitudes 7° and 30° N., and the south trades between latitudes 3° N. and 25° S. These limits are not stationary, but follow the sun, being farthest to the south in February and to the north in August. The tract of low pressure between these wind systems is named the region of calms, owing to the calm weather which often prevails there, and it is also characterized by the frequent occurrence of heavy rains. This region of calms varies its position with that of the sun, reaching its most northern limit lat. 11° N..

in August, and its most southern lat. 1° N., in February. Its breadth varies from 3° to 8°, and it lies generally parallel to the equator. It is to be noted that, in the Atlantic, the region of calms is at all seasons north of the equator.

North and south trades also prevail in the Pacific Ocean separated by a region of calms, which would appear, however, to be of less breadth and to be less clearly defined than is the region of calms in the Atlantic. In the eastern portion of the Pacific the region of calms lies at all seasons to the north of the equator, but in the western division it is considerably south of the equator during the summer months of the southern hemisphere, this southerly position being in all likelihood occasioned by the extraordinarily high pressure in Asia in its relations to the low pressure in the interior of Australia at this season. During the summer months of the northern hemisphere the region of calms wholly disappears from the Indian Ocean and from the western part of the Pacific Ocean, there being then an unbroken diminishing pressure from the latitude of Mauritius and Central Australia northwards as far as the low pressure of Central Asia.

Regions of light and variable winds and calms occur at the higher limits of the north and south trades. Except in the Pacific, where owing to the greater breadth of that ocean they spread over a considerable extent, these regions appear but in circumscribed patches, such as characterize the meteorology of the North and South Atlantic about latitudes 26° to 36°. Of these regions of calms the most important is that marked off by the high pressure in the North Atlantic between the United States and Africa. This is the region of the Sargasso Sea where the weather is characterized by calms and variable winds and the ocean by its comparatively still waters. These are known to seamen as the "horse latitudes," and are essentially different from the equatorial region of calms. The latter, as has been stated, is the region of low pressure at the meeting of the north and south trades where the climate is distinguished for its general sunlessness and heavy rainfall. On the other hand the calm regions in the Atlantic and Pacific Oceans about the tropics have an atmospheric pressure abnormally high, clear skies, and the weather generally sunny and bright with occasional squalls.

Numerous observations made in all parts of the globe establish the fact that while the surface winds within the tropics are directed towards the equatorial region of calms in such a manner that the general intertropical movements of the atmosphere or prevailing winds are easterly, the prevailing winds of the north and south temperate zones are westerly. The westing of these great aerial currents is due to the same cause that gives easting to the trade winds, viz., the rotation of the earth round its axis. For, as an aerial current advances into higher latitudes it is constantly arriving at regions having a less rotatory velocity than itself; it thus outstrips them and leaves them behind, in other words it blows over these places as a westerly wind.

While however the general prevalence of westerly winds has been established over the extratropical regions of Europe, Asia, Africa, America and Australia, the directions which in different seasons and at different places are actually found to prevail often differ very widely from west. An examination of the winds at one hundred and fifteen places pretty well distributed over the northern hemisphere reveals the instructive fact that almost every place shows two maximum directions from which winds blow more frequently than from the other directions, and that one of these two directions shows a considerable excess over the other. Thus, for example, the following are, on a twenty years' average, the number of days at Greenwich each wind prevails during the year:—N., 41, N.E., 49, E., 23, S.E., 21, S., 34, S.W., 103, W., 38, N.W., 24, and calms, 32. Hence S.W. and N.E. winds are there more prevalent than winds from any other direction, and of these two winds the greater maximum direction is S.W. If the two maximum directions be sorted into groups, then the greater maximum direction occurs as follows:—

from S.S.W. to W. at 47 places.
W.N.W. „ N. „ 33 „
N.N.E. „ E. „ 19 „
E.S.E. „ S. „ 16 „

and the other maximum direction is

from S.S.W. to W. at 20 places.
W.N.W. „ N. „ [illegible] „
N.N.E. „ E. „ 38 „
E.S.E. „ S. „ 32 „

This result of observation, so different from what was long accepted as being in accordance with the generally received theory of the movements of the atmosphere, teaches the important lesson that the region towards which the extra-tropical winds of the northern hemisphere are directed is not the region of the north pole.

Prevailing Winds in January.—On examining fig. 14, which shows the distribution of atmospheric pressure in January, it is seen that pressure is abnormally low over the northern portion of the Atlantic—the lowest occurring between Iceland and South Greenland—from which it rises as we proceed in a S.W. direction towards America, in a S. direction over the Atlantic, and in a S.E. and E. direction over Europe and Asia. Now what influence has this remarkable atmospheric depression on the prevailing winds over this large and important part of the earth's surface? The arrows in the figure which indicate the prevailing winds, and which have been laid down from observations, answer this question.

At stations on the east side of North America the arrows show a decided predominance of north-west winds; at the more northern places the general direction is more northerly, whereas farther south it is more westerly. In the Atlantic between America and Great Britain, in the south of England, in France and Belgium, the direction is nearly S.W. In Ireland and Scotland it is W.S.W.; in Denmark and the north-west of Russia S.S.W.; from St Petersburg to Tobolsk S.W.; on the west of Norway generally S.S.E.; and in Greenland, the north of Iceland, and about Spitzbergen N.E. Hence all the prevailing winds in January over this extensive portion of the globe may be regarded as the simple expression of the difference of atmospheric pressure which prevails over the different parts of the region. In truth the whole appears to flow vorticosely, or in an in-moving spiral course towards the region of low pressure lying to the south-west of Iceland, and extending eastward over the Arctic Sea north of Russia. The only marked changes in these directions of the wind thus broadly sketched out are the deflexions caused by the various mountain systems which lie, so to speak, embedded in these vast aerial currents; of these the winds in the south of Norway afford excellent illustrations.

The influence which this peculiar distribution of the pressure over the north of the Atlantic exercises in absolutely determining the winter climates of the respective countries is most instructive. It is to this low pressure, which draws over the British Islands W.S.W. winds from the warm waters of the Atlantic, that the open, mild, and, it must be added, rainy winters of these islands are due. The same region of low pressure gives Russia and Western Siberia their severe winters; and it is the same consideration that fully explains the enormous deflexion of the isothermal lines from Norway eastwards and south-eastwards over the Old Continent Finally, the same low pressure draws over British America and the United States, by the N W winds which it induces, the intensely dry cold air current of the Arctic regions At Portland, Maine, which is swept by these cold north westerly winds, the normal temperature in January is 23° 6, whereas at Corunna, on the coast of Spain, in nearly the same latitude, where south westerly winds from the Atlantic prevail the mean temperature of the month is 49° 1, or 25° 5 higher

The region of low atmospheric pressure in the north of the Pacific is accompanied by prevailing winds over the region embraced by it and by climatic effects in all respects similar to the above In Vancouver Island the prevailing winds in January are S W, at Sitka E S E on Great Bear Lake E N E, in Alaska N E, in Kamchatka N N E, and in Japan N W In accordance with these winds the winter climate of Vancouver and adjoining regions is mild and humid, and that of the north east of Asia dry and intensely cold

On the other hand, abnormally high pressure rules over the continent of Asia at this season, and as regards this region of high pressure the arrows represent the winds as blowing outwards from it in all directions Over the interior of Asia, where the highest normal pressures are observations show a marked prevalence of calms and light winds but around this central region the prevailing winds in January are—at Calcutta N, at Hong Kong E N E, at Peking N W, on the Amur W N W S E at Nijnikolymsk and S S W at Ustjansk (in the north of Siberia), and at Bogoslovsk S W Hence from this extensive region where pressure is abnormally high, or where at this season there is a large surplus of air the prevailing winds flow outwards in all directions towards the lower pressure which surrounds it Owing to the excessive dryness of the air of Central Asia terrestrial radiation is less obstructed there than anywhere else on the globe, and consequently the temperature falls very low the mean of January at Werchojansk being − 53° 8 which is the lowest mean monthly temperature known to occur on the earth's surface And, since the winds blow outwards from the dry cold climates of the interior temperatures are low even on the coasts Of this China affords good illustrations Thus the mean January temperature of Peking is 22 7 and of Zi ka Wei near Shanghai 35 4 whereas at Corfu and Alexandria the normal temperatures for January are respectively 50° 9 and 58 0 or 28 2 and 22 6 higher than in corresponding latitudes on the coast of China

The winds of the United States in winter taken in connexion with the peculiar distribution of pressure already described, are very interesting There are two regions of high pressure one in the south eastern States and the other and larger one in the region round Utah and between these there is interposed a trough of lower pressure extending from Chicago to the south west of Texas On the western side of this depression the winds are north westerly, but to the east of it they become W, W S W and in some places S W, and again on nearing the Atlantic seaboard they become north westerly In connexion with the region of higher pressure in the west, the prevailing winds are seen to flow outward from it The normal pressure diminishes everywhere to southward of a line drawn from the Canaries to Bermuda, thence westward in nearly the same latitude to Texas and then to west north west to San Francisco The tract of lowest pressure stretches from the basin of the Amazon in the direction of the isthmus of Panama in about latitude 8 N, and thence is continued westward for a considerable distance into the Pacific in nearly the same latitude It follows from this distribution of the pressure that the north trades in a more or less modified form prevail over South America to the north of the Amazon, and in the Pacific to the north of lat 8° N, probably as far to westward as long 150° W

The low pressure systems which prevail during the summer months in South America and South Africa have each its corresponding system of winds all round It is however, in Australia, as being the most compact and isolated continent that the influence of the summer sun in lowering the pressure is best illustrated In that continent the lowest pressure occurs in the region situated about midway between the north coast and the tropic of Capricorn, over which the normal pressure does not exceed 29 80 inches Further, everywhere in Australia pressure diminishes from the coast on advancing upon the inland districts It follows from this disposition of the pressure that all round the island the prevailing winds in summer blow from the sea towards the interior and accordingly it is in these months that the greater part of the rain falls From the low pressure of the interior southwards to Bass's Straits pressure rises continuously the increase in the normal over this space being about 0 200 inch To northward it also rises continuously to beyond the north of China, the increase on this side being about ¾ of an inch In this case the greater part of the increase occurs over the continent, the rate of increase from the north of Australia to the Philippine Islands being only about the rate of increase which obtains southward towards Bass's Straits It will be shown when the subject of the rainfall is examined that it is the relative excess of these high pressures the one in the south of Australia and the other in the south east of Asia that determines the position of the area of low pressure in Australia in particular years, and with that position the degree and extent to which the whole of the northern portion of Australia is watered by the rainfall Thus when pressure is more than usually high in the south east of Asia and either low or not excessive in the south of Australia then the low pressure region is pushed farther southward into the interior, and with it the rainfall spreads inland over a wider area and to a greater depth

Prevailing Winds in July—In the winter of the southern hemisphere the geographical distribution of pressure is exactly the reverse in Australia of what obtains during the summer months Everywhere all round it increases on advancing from the coast into inland districts The lowest pressure about 30 00 inches occurs on the north coast and the highest over the basin of the Murray river and its affluents where it rises generally to 30 18 inches On the south coast it is generally about 30 12 inches falling however at Gabo Island in the extreme south east to 30 050 in he and to 29 956 in the south of New Zealand From the Murray river the diminution of pressure is continuous to the north even to the low pressure of Central Asia From this arrangement of the pressure the prevailing winds flow from the interior toward the surrounding ocean all round Australia with the single exception of the extreme south west of the continent where the prevailing winds are south westerly being here essentially an outflow of the high pressure which overspreads the Indian Ocean to the westward As these S W winds are from the ocean, the rainfall at Perth in July is fully 6 inches and it is high over south western districts of West Australia The prevailing winds round Australia are S E on the north coast S W at Brisbane, W N W at Sydney N at Melbourne, N E at Adelaide These all represent an outflow from the high pressure regions of the interior modified by the influence of the earth's rotation and in correspondence with the reversal of the distribution of the pressure, are directions the reverse of the prevailing winds of January

In July the central and southern parts of Asia are highly heated by the summer sun and, besides, the rainfall over southern parts is excessive Consequently atmospheric pressure is very low being fully 0 40 inch lower in the Punjab than it is in the south of Ceylon From the interior pressure rises continuously on advancing to the eastward, southward westward and northward, and from all these directions the prevailing winds of summer flow inwards upon the interior and these bring rain or parching drought according to the vapour they bring from the ocean they have traversed and according as they advance into warmer or colder regions The prevailing summer winds of Asia being an inflow inwards upon the interior, have generally speaking exactly the reverse direction of that prevailing in winter

The winds of Europe are mainly determined by the extraordinarily high pressure of the Atlantic in its relations to the low pressure systems of Central Asia and Central Africa at this time The winds in the Spanish Peninsula are north west in the north of Africa they are northerly, and again north westerly in Syria The winds of the British Islands and western Europe have less southing and more northing than the prevailing winds of winter and to the east of long 40 E they become decidedly north west It is to the Atlantic origin of these winds that the summer climates of these large and important regions owe the comparatively large rainfall of this season it being at this time that the rainfall reaches the annual maximum The bearing of the low pressure areas and mountain systems of the north of Italy and Scandinavia on the climates of these countries will be afterwards referred to

The centre of lowest pressure in North America is over desert about Utah from which it rises all round least to northward and most in south easterly and north westerly direction In California N W winds necessarily blow inwards upon this central low pressure area and as these winds pass successively over regions the temperature of which constantly increases the summer climate is rainless On the other hand southerly and south easterly winds from the Gulf of Mexico blow up the western side of the basin of the Mississippi inwards upon the low pressure area of the centre depositing in their course in a rainfall more or less abundant the moisture they have brought from the Gulf To the north of lat 50 and to westward of Hudson's Bay the prevailing winds become easterly and north easterly distributing over Manitoba Saskatchewan and neighbouring region as they continue their westerly course towards the low pressure area the rainfall they have transported thither from the wide expanse of Hudson's Bay An attentive examination of the arrows of fig 17 shows that the prevailing winds over all the States to the east of the Mississippi river are rather to be regarded as an outflow from the region of very high pressure over the Atlantic to south eastward Thus in Florida the winds are S E in the southern States S, and in the like region in the New England States and on the Atlantic seaboard S W Since the origin of these winds is thus essentially oceanic and since in their course northwards no mountain range crosses their path the whole of this extensive region enjoys a large but by no means excessive rainfall, which taken in connexion with the temperature renders the summer climate of these States one of the best to be met with anywhere on the globe for the successful prosecution of agricultural industries

The remarkable protrusion of high pressures from the southern hemisphere where they are massed at this time of the year northwards into the Atlantic is as has already been referred to, one of the outstanding features of the meteorology of the summer months of the northern hemisphere In the central area of this large region the climate is remarkable for its prevailing calms light winds, occasional squalls, and clear skies From this comparatively calm space the wind blows outwards in all directions towards and in upon the surrounding regions of low pressure These winds, owing to the high temperature, clear skies, and strong sunshine of the region from which they issue, carry with them a great amount of vapour near the surface, by which to a large extent the north of South America, the east of North America, the greater part of Europe, and a large portion of Africa are watered The prevailing winds over this region are further interesting, not merely from the striking illustration they give of the intimate relation of the winds to the distribution of the pressure but as being of no small importance in determining the best routes to be taken over this great highway of commerce and the more so inasmuch as the currents of the ocean are coincident with these prevailing winds

In the Antarctic regions, or rather to the south of lat 45° S, the normal atmospheric pressure is low at all seasons there being a gradual diminution of pressure to 29 20 inches about lat 60° S Pressure is probably even still lower nearer to the south pole, as seems to be indicated by the observations made by Sir James C Ross, and in the "Challenger and other expeditions Over this zone the prevailing winds are W N W and N W This is the region of the brave west winds the roaring forties' of sailors which play such an important part in navigation, and which determine that the outward voyage to Australia be round the Cape of Good Hope and thence eastward, and the homeward voyage eastward round Cape Horn the globe being thus circumnavigated by the double voyage That the general drift of these winds is inwards upon the south pole is strongly attested by the existence of the enormously thick wall of ice which engirdles these regions, from which are constantly breaking away the innumerable icebergs that cover the Southern Ocean none of which is ever seen of a calculated thickness less than 1400 feet The snow and rainfall which must take place in the south polar regions for the formation of icebergs of such a thickness must be peculiarly heavy but not heavier than might be expected from the strength and degree of saturation of the 'roaring forties which unceasingly precipitate their moisture over these regions

To sum up — so far as the prevailing winds are concerned it has been shown that where pressure is high that is to say where there exists a surplus of air out of such a region winds blow in all directions and on the other hand where pressure is low or where there is a deficiency of air towards such a region winds blow from all directions in an in moving spiral course This outflow of air currents from a region of high pressure upon a region of low pressure is reducible to a single principle viz the principle of gravitation Given as observed facts the differences of pressure it is easy to state with a close approximation to accuracy what are the prevailing winds before calculating the averages from the wind observation Indeed so predominating is the influence of gravitation where differences of pressure however produced exist that it may practically be regarded as the sole force immediately concerned in causing the movements of the atmosphere If there be any other force or forces that set the winds in motion independently of the force called into play by differences of mass or pressure their influence must be altogether insignificant as compared with gravitation

It has been abundantly proved that the wind does not blow directly from the region of high towards that of low pressure but that in the northern hemisphere the region of lowest pressure is to the left of the direction towards which the wind blows, and in the southern hemisphere to the right of it This direction of the prevailing wind with reference to the pressure is in strict accordance with Buys

Ballot s Law of the Winds, which may be thus expressed — the wind neither blows round the centre of lowest pressure in circles, or as tangents to the concentric isobaric curves of storms or cyclones, nor does it blow directly towards the centre but it takes a direction intermediate, approaching, however, more nearly to the direction and course of the circular curves than of the radii to the centre The angle formed by a line drawn to the centre of lowest pressure from the observer s position and a line drawn in the direction of the wind is not a right angle, but an angle of from 60 to 80

From its importance in practical meteorology Buys Ballot s law may be stated in these two convenient forms (1) Stand with your back to the wind and the centre of the depression or the place where the barometer is lowest will be to your left in the northern hemisphere and to your right in the southern hemisphere This is the rule for sailors by which they are guided to steer with reference to storms (2) Stand with the high barometer to your right and the low barometer to your left and the wind will blow on your back these positions in the southern hemisphere being reversed It is in this form that the prevailing winds of any part of the globe may be worked out from the isobaric charts (figs 14 and 17)

From the all important consequences which flow from the geographical distribution of the pressure it is evident that the regions of low and of high normal pressure must be regarded as the true poles of the prevailing winds on the earth s surface towards which and from which the great movements of the atmosphere proceed From the unequal distribution of land and water and their different relations to solar and terrestrial radiation, it follows that the poles of pressure and of atmospheric movements are just as happens with respect to the poles of temperature very far from being coincident with the north pole Thus during the winter months the regions to which the origin of the great prevailing winds of the northern hemisphere are to be referred are Central Asia the region of the Rocky Mountains and the horse latitudes of the Atlantic and the regions towards and in upon which they flow are the low pressure systems in the north of the Atlantic and Pacific Oceans and the tract of low pressure within the tropics towards which the trade winds blow In the summer months the reversed conditions of pressure-distribution then observed are attended with corresponding changes in the prevailing winds and generally speaking if the south polar region be excepted the poles of highest and lowest pressure and atmospheric movements are at no time coincident with the north pole It is this consideration which affords the true explanation why prevailing winds at so large a proportion of stations in the northern hemisphere do not blow in the directions in which true equatorial and polar winds should blow

The causes which bring about an unequal distribution of the mass of the earth s atmosphere are mainly these two— the temperature and the moisture of the atmosphere considered with respect to the geographical distribution of land and water Owing to the very different relations of land and water to temperature as already stated the summer temperature of continents greatly exceeds that of the ocean in the same latitudes Hence the abnormally high temperature which prevails in the interior of Asia, Africa, America, and Australia during their respective summers, in consequence of which the air becoming specifically lighter ascends in enormous columns thousands of miles in diameter On arriving at the higher regions of the atmosphere it flows over neighbouring regions where the surface temperature is lower, and thus the atmospheric pressure of the highly heated regions is diminished

Surface winds set in all round to take the place of the air removed from the continents by these ascending currents, and since these necessarily are chiefly winds from the ocean they are highly charged with aqueous vapour, by the presence of which, and by the condensation of the vapour into cloud and rain, the pressure over continents at this season is still further and very largely diminished Air charged with vapour is specifically lighter than when without the vapour in other words the more vapour any given quantity of atmospheric air has in it the less is its specific gravity and further the condensation of vapour in ascending air is the chief cause of the cooling effect being so much less than that which would be experienced by dry air From the above principles, which were established by Dalton Joule and Sir William Thomson it follows that the pressure of vapour in the air, and its condensation exercise a powerful influence in diminishing the pressure The great contributing influences at work in the atmosphere are the forces called into play by its aqueous vapour and it is to these co operating with the forces called into play by the differences of temperature directly that the low normal pressure on the continents during the summer is to be ascribed The degree to which the lowering of the pressure takes place is as was to have been expected greatest in Asia the largest continent and least in Australia the smallest continent while in America it is intermediate

The influence of the aqueous vapour in diminishing the pressure is well seen in the belt of calms in the tropics between the north and the south trade winds Since these winds import into the belt of calms the vapour they have taken up from the sea on their way thither the climate is characterized by a highly saturated atmosphere and heavy rains Again the air in regions near the Atlantic contains much more vapour and is of a higher temperature during winter than is observed at places in the interior of continents in the same latitudes It follows thus that the air over the north of the Atlantic and the region adjoining is specifically lighter than in the regions which surround them We have here therefore the physical conditions of an ascending current and it is plain that the strength of this current will not merely be kept up but increased by the condensations of the vapour into cloud and rain which take place within it by which a higher temperature and a greater specific lightness are maintained at the surface of the earth and at various heights in the atmosphere than exist over surrounding regions at the same heights Accordingly it is seen from the winter isobars that an enormous diminution of pressure occurs over these regions, and also over the north of the Pacific and the Antarctic, as compared with the continents

Since on the other hand, dry and cold air is specifically heavy the winter isobars show that where temperature is low and the air very dry pressure is high Of this Asia and North America are striking examples during December, January and February and Australia South Africa and South America during June July and August

Since vast volumes of air are thus poured into the region where pressure is low without increasing that pressure and vast volumes flow out of the region where pressure is high without diminishing that pressure it necessarily follows that the volumes of air poured into the region of low normal pressure do not accumulate over that region but must somehow escape away into other regions and that the volumes of air which flow out from the region of high normal pressure must have their place supplied by fresh accessions of air poured in from above That the same law of relation observed between sea level pressures and surface winds obtains between pressures at different heights and winds at the same heights is simply a necessary inference We are therefore justified in expecting that ascending currents will continue their ascent till a height is attained at which the pressure of the air composing the currents equals or just falls short of the pressure over the surrounding regions at that high level. On reaching this height the air, no longer buoyed up by a greater specific levity than that of the surrounding air, will cease to ascend, and expanding horizontally will thenceforth flow over as an upper current towards those regions which offer the least resistance to its course, that is to say, it will flow over upon those regions where, at that height, pressure happens at the time to be least. Now from the known densities of air of different temperatures and humidities it is evident that the overflow of the upper current will take place towards and over that region or regions the air of which in the lower strata of the atmosphere happens to be colder and drier than that of the other surrounding regions,—because, being denser, a greater mass of air is condensed or gathered together in the lower strata of the atmosphere, thus leaving a less mass of air or a diminished pressure, in the higher region of the upper current.

If this be so, then the extraordinarily high pressure of Central Asia during winter is to be ascribed to these two causes:—(1) the low temperature and excessive dryness of the air of this extensive region; and (2) its relative proximity to the low pressure of the Atlantic to the north-west, the low pressure of the Pacific to the north-east, and the low pressure of the belt of calms to the south. Similarly, since in summer the temperature of air resting over the Atlantic between Africa and the United States is much lower than that of the land, the ascending currents which arise from the heated lands of Africa, Europe, and North and South America, as well as from the region of calms immediately to the south, all of which are remarkable for a low normal pressure, will on reaching the upper regions of the atmosphere flow towards this part of the Atlantic, because there, the temperature being lower and the density of the air composing the lower strata being greater, pressure in the upper region is less. And, since the surface winds are constantly flowing outwards from this region of abnormally high pressure, thus draining away the air poured down upon it by the upper currents which converge on it, extreme saturation does not take place, and the air is [illegible] relatively dry and cool. That this view generally represents the movements of the upper currents [illegible] strikingly confirmed within the last few years by [illegible] Hildebrandsson and Clement Ley in their researches [illegible] the atmosphere has been closely [illegible] the [illegible].

From these considerations it may be concluded that the winds which prevail [illegible] are known from the [illegible] direction of the wind [illegible] from regions where [illegible] towards regions where it is low, in accordance with Buys Ballot's law; and that the upper currents may be inferred from the isobaric lines taken reversely, together with the isothermal lines taken directly. In other words the regions of lowest pressure, with their ascending currents and relatively higher pressure at great heights as compared with surrounding regions, point out the sources or fountains from which the upper currents flow; and the [illegible] showing where, on account of the relatively low temperature, the greater mass of the air is condensed in the lower strata of the atmosphere and sea-level pressure consequently is high, thus diminishing the pressure of the upper regions, point out the regions towards and upon which these upper currents of the atmosphere flow. The facts of the diurnal oscillations of the barometer in the different regions already discussed afford the strongest corroboration of these views.

The term "monsoon" has long been applied to the prevailing winds in southern Asia which blow approximately from S.W. from April to October, and from N.E. from November to April. The term is now, however, generally applied to those winds connected with continents which are of seasonal occurrence, or which occur regularly with the periodical return of the season. Since they are caused immediately by the different temperatures and pressures which form marked features of the climates of continents in winter and summer respectively, they are most fully developed round the coast of Asia, owing to the great extent of that continent. The monsoons of different parts of the coasts of Asia differ widely in direction from each other. Thus in winter and summer respectively they are W.N.W. and E.N.E. at the mouth of the Amur, N. and S.S.E. at Shanghai, N.E. and S.W. at Rangoon, N. and W.S.W. at Bombay, N.W. and S.W. at Jerusalem, and S.S.W. and N.N.E. at Archangel. The Indian winter monsoon generally begins to break up in March, but it is not till about the middle of May, when the normal pressure has been decidedly diminished over the heated interior, that the summer monsoon acquires its full strength and the heavy monsoonal rains fairly set in. In October, when the temperature has fallen considerably and with the falling temperature the pressure of the interior has risen, the summer monsoon begins to break up, and this season is marked by variable winds, calms, and destructive hurricanes. As the temperature continues to fall and pressure to rise the winter monsoon again resumes its sway. Monsoons, equally with the trade winds, play a most important part in the economy of the globe. The relatively great force and steadiness in the direction in which they blow, and the periodical change in their direction, give facility of intercourse between different countries; and, besides, by the rainfall they bring they spread fertility over extensive regions which otherwise would be barren wastes.

The winds of Australia are also strictly monsoonal, but owing to the small extent of that continent, and consequently the smaller differences there are between the normal pressure of the interior and that of the surrounding coasts in summer and winter respectively, they are less strongly marked than are the monsoons of southern Asia, and particularly they neither blow with the same force nor so steadily from the same point of the compass. For the same reason the Australian climates are characterized by the occurrence of more frequent droughts than are the climates of southern Asia and the same remark applies to the climates of southern Africa.

Since the Malay archipelago lies during the summer of the northern hemisphere between the high pressure of central Australia and the low pressure of Asia, and during the winter between the high pressure of Asia and the low pressure of central Australia, it follows that the winds of these islands are eminently monsoonal in their character, being in summer southerly and in winter northerly. The result of this peculiar wind system of the archipelago is to give to these islands a singular diversity of climates, which will be more particularly referred to under rainfall.

At Zanzibar the prevailing wind in July is S.E., but in January, when the low pressure of the interior is situated much farther to southward, it is N.E. and the same influence is felt, though in a greatly modified degree, as far as Mauritius, where the S.E. trade changes nearly into E. during the summer. On the other side of Africa the S.E. trade of the South Atlantic is changed into a S.W. monsoon on the coast of the Gulf of Guinea.

In the southern, central, western, and northern regions of North America the prevailing winds have a well marked monsoonal character. The prevailing winds of winter and summer respectively are N.E. and S.S.E. at New Orleans, NW. and SW in Utah, N and S at Fort Yuma (California), ESE and NW at Portland (Oregon), and S and ENE at Fort York, Hudson Bay These winds are readily accounted for by the distribution of pressure over the continent in winter and summer On the Atlantic seaboard of the United States the prevailing winds of winter vary from NW in the New England States to W in South Carolina, whereas in summer they vary generally from SSW in South Carolina to SW in the New England States Hence over the eastern States the summer winds are not directed towards the low pressure region of the interior of the continent, but are determined by the relations of their pressure to the high pressure of the Atlantic to the eastward, and to the lower pressure over spreading the Atlantic to the NE This influence of the Atlantic may be considered as felt westward through the States as far as the Mississippi.

Though not so decidedly marked, the winds of Europe, except the extreme south, are also monsoonal In winter they flow from the land towards the region of low pressure in the north of the Atlantic, but in summer the arrows, representing the prevailing winds, show that all but the extreme south of Europe is swept by westerly winds, which flow in a vast continuous stream from the Atlantic towards the central regions of the Old Continent, and which deposit in their course the rains they have brought from the ocean

Similarly, monsoons prevail on the coasts of Brazil, Peru, North Africa, and many other regions which happen to lie between other regions whose temperatures, and therefore pressures, differ markedly from each other at different times of the year

These are the chief prevailing winds of the globe when the differences of the normal atmospheric pressure are such as to cause a decided and steady movement of the atmosphere over a large portion of the earth's surface, resulting in well marked prevailing winds But there are other winds which are greatly influenced by local causes, such as the nature of the ground, whether covered with vegetation or bare, the physical configuration of the surface, whether level or mountainous, and the vicinity of extensive sheets of fresh or salt water An important characteristic of winds in their practical relations to climate is their quality,—they being warm or cold, dry or moist, according to their direction and the nature of the earth's surface over which they have just passed Thus in the northern hemisphere southerly winds are warm and moist, while northerly winds are cold and dry In Europe south westerly winds are moist and easterly winds dry, while in the New England States and Canada north easterly winds are cold and raw and north westerly winds cold and dry

In particular regions certain meteorological conditions occur at stated seasons intensifying these effects, resulting in excessive drought, heavy rains, intense or great heat, thus giving rise to the following among other well known winds The east winds of the British Islands occur chiefly in spring, but also in a less degree in November, being in the latter case often accompanied with fog The winds here referred to are dry and parching, and their deleterious influence on the health is seen, not merely in the discomfort and uneasiness they impart to the less robust of the population, but also in the largely increased mortality which they cause from consumption and all other diseases more or less connected with the nervous system In the countries bordering on the north of the Atlantic, atmospheric pressure reaches the annual maximum in May, and it is above the average during the other two spring months In these months the normal pressure approaches nearer to what obtains farther south, and an examination of daily weather maps shows that this is due to the repeated occurrence in spring of very high pressures in the north of Europe while pressures much lower prevail to southward Now these east winds are simply the outflow from these regions of high pressure to northward Northerly and even westerly winds which are truly outflows from what may be styled Arctic anticyclonic areas bring with them qualities as noxious as those of the east wind itself, and prove as injurious to health and vegetation The cold dry wind of April 29, 1868, which blasted and shrivelled up vegetation in Scotland, particularly in the western counties, as effectually as if a scorching fire had passed across them, was a west wind

In the south of Europe during the winter and early spring, peculiarly dry, cold, and violent northerly winds are of occasional occurrence Of these winds the mistral is one of the most notorious which is a steady violent and cold north west wind blowing from central and eastern France down on the Gulf of Lyons It is particularly trying while it lasts to invalids who are spending the winter at the various popular sanatoria which are scattered along this part of the Mediterranean coast The great cold that took place in the north of Italy and south of France in the beginning of 1868 was a good example of the mistral The meteorological conditions under which it [illegible] unusually low pressure over the Mediterranean and southward (29·100 inches), while at the same time pressure rose steadily and rapidly on proceeding northward to 30·300 inches in the north of Russia From this geographical distribution of the pressure northerly winds swept southwards over Europe carrying with them the low temperature of the higher latitudes and became still colder and drier on crossing the Alps before they made their descent on the slopes of the Mediterranean The [illegible] tempestuous wind which blows from the Julian Alps and sweeps down on the Adriatic, and the dreaded gregale of Malta, which [illegible] similar in their character and in [illegible]

The [illegible] winds which frequently [illegible] the Mediterranean States, [illegible] of M[illegible] the [illegible] The [illegible] Gulf of Mexico, together with a [illegible] is so marked a feature of the [illegible] during the colder months When [illegible] in the wake of a [illegible] temperature of upwards of 80° experienced as the storm [illegible] the thermometer rapidly falls to 18° or even lower [illegible] temperature often occurs with a wind blowing with great violence the northers prove most deleterious A violent wind with a temperature of 18° is altogether unknown in the British Islands

The "pampero" is a strong, dry, cold wind which blows across the pampas of the River Plate of South America, occurring at all seasons, but most frequently during the spring and summer from October to January They are preceded by easterly winds, a falling pressure, a rising temperature and increased moisture A pampero is described by Dr D Christison and its appearance figured in the *Journal of the Scottish Meteorological Society*, vol v p 342 as seen advancing on the morning of November 28 1867 in central Uruguay In the early morning the wind blew rather strongly from north east and by and by clouds were seen moving very slowly from the west throwing out long streamers eastwards As they advanced two dense and perfectly regular cloud masses appeared in front one behind the other in close contact yet not intermingling —the one being of a uniform leaden grey while the other was as black as the smoke of a steamer On arriving over [illegible] quite straight in its ge[illegible] breadth They rushed forward at great speed under the other clouds without uniting with them preserving their forms unbroken being borne onward by an apparently irresistible force as if composed of some solid material rather than vapour They extended probably 50 miles in length but as they took only a few minutes to pass their breadth was not great and they appeared to diminish to mere lines in the distant horizon At the instant the first cloud band arrived overhead the wind chopped round from north east to north and then to south west a strong cold blast at the same time seemed to fall from the leaden cloud and continued to blow till both bands had passed No rain or thunder occurred at this time but in the confused rabble of clouds which followed low thunder continued to roll, and in a quarter of an hour rain fell and for some hours thereafter wind rain and thunder continued but only to a moderate degree The low temperature and rising barometer and change of wind are the constant and most striking characteristics of the pampero On one occasion the temperature fell 44° in fourteen hours, and on another occasion the fall was only 4° Rain is a usual accompaniment, but on rare occasions the pampero passes off and no rain falls

Rainfall.—Whatever tends to lower the temperature of the air below the dew point is a cause of rain. It is therefore to the winds we must chiefly look for an explanation of the rainfall, and the broad principles of the connexion may be stated to be these five:—(1) when the winds have previously traversed a considerable extent of ocean, the rainfall is moderately large; (2) if the winds advance at the same time into colder regions, the rainfall is largely increased, because the temperature is sooner reduced below the point of saturation; (3) if the winds, though arriving from the ocean, have not traversed a considerable extent of it, the rainfall is not large; (4) if the winds, even though having traversed a large extent of ocean, yet on arriving at the land proceed into lower latitudes or regions markedly warmer, the rainfall is small or nil; (5) if a range of mountains lies across the onward path of the winds, the rainfall is largely increased on the side facing the winds, and reduced over the regions on the other side of the range. The reason here is that, the air on the windward side of the ridge being suddenly raised to a greater height in crossing the range, the temperature is further reduced by mere expansion, and a more copious precipitation is the result; whereas on the leeward side as the air descends to lower levels it becomes gradually drier, and accordingly the rainfall rapidly diminishes with the descent.

We have drawn attention to the diminished velocity of the wind over land as compared with the open sea (p. 125). From this it follows that an envelope of stiller air or air of less velocity than that of the prevailing wind broods over the land, and by its presence forces the prevailing wind to a greater height, thus tending to increase the rainfall. If the foreshore rises within a few miles to a height of 200 or 300 feet, the result is very striking when the wind from the sea blows straight upon it. Thus at Spittal, near Berwick, on September 1877, a N.E. wind blew straight ashore at an estimated velocity of 25 miles an hour. To eastward the sky was singularly clear down to the horizon, but to westward all the country beyond a mile from the shore was enveloped in what appeared a dense mist or fog. About 15° to eastward of the zenith of an observer on the shore the thinnest rack of cloudlets was seen emerging without intermission from the deep stainless blue of the sky, which as it drifted landward increased so rapidly in volume and density that the zenith was three-fourths covered with clouds. A similar phenomenon was seen in September 1879 on board the Orkney steamer at the magnificent cliff of Hoy Island, Orkney. A heavy storm had just cleared away, and a strong W.N.W. wind was blowing right against the cliff. The sky was absolutely cloudless all round, except the upper 300 feet of Hoy Hill, 1570 feet high, which was enveloped in a thick mist that stretched away to windward some distance to westward of the steamer's course, which was about 2 miles from land. The western termination of the cloud was the thinnest rack of cloud which emerged unceasingly from the blue sky at a distance not less than 4 miles to windward of the cliff. The constituent parts of the cloud itself were in rapid motion eastward, but owing to the fresh accessions it was constantly receiving the cloud itself appeared stationary. Thus the wind was forced upward into the atmosphere for some considerable distance to windward of the ridge lying across its path.

It is this dragging effect of the land on the wind and the consequences which result from it that explain how it is that during storms of wind and rain from the north-east the rainfall over the foreshores of the Firth of Forth, the Moray Firth, and the Pentland Firth looking to the north-east is so much in excess as compared with the rest of Scotland. The same principle explains the heavy rainfall in the lowlands some distance from the range of hills lying across the wind's path and on the side of the rain-bringing winds.

For short intervals of time the heaviest rainfalls occur with tornadoes, waterspouts, and some other forms of the whirlwind, the reason being that not only is there rapid expansion due to the rapid ascent of the air, but also great rarefaction is produced by the extreme velocity of the aerial gyrations round the axis of the tornado. On August 1, 1846, 3·12 inches of rain fell at Camberwell, London, in two hours and seventeen minutes. Of heavy falls may be mentioned 4·60 inches in London, April 13, 1878; 6·00 inches at Tongue, September 7, 1870; 5·36 inches in Monmouthshire, July 14, 1875; 6·62 inches at Seathwaite, Cumberland, November 27, 1848; and 7·12 inches at Drishaig, Argyllshire, December 7 to 8, 1863. But it is in lower latitudes that the heaviest single showers have been recorded. The following are among the most remarkable:—at Joyeuse, France, 31·17 inches in twenty-two hours; at Genoa, 30·00 inches in twenty-four hours; at Gibraltar, 33·00 inches in twenty-six hours; on the hills above Bombay, 24·00 inches in one night; and on the Khasi Hills, India, 30·00 inches on each of five successive days.

As regards the ocean, there are no available data from which an estimate could be formed as to the amount of the rainfall, since the rainfall statistics of the ocean must be regarded as giving hardly anything more than the comparative frequency of the fall. It is, however, certain that the equatorial belt of calms in the Atlantic and Pacific between the trades is the region where the ocean rainfall reaches the maximum, and the parts of these oceans are the rainiest which are the longest within the belt of calms as it shifts its position northward and southward with season. While the cloud screen is undoubtedly dense, and the rainfall frequent and heavy, the careful observations of the "Challenger" and "Novara" show that the statements generally made as to these points are greatly exaggerated.

In the regions of the trades the rainfall is everywhere small over the open sea, seeing that the trade winds are essentially an outflow from anticyclonic regions, and their original dryness is to a large extent maintained because their course is directed into regions which become constantly warmer. Thus at Ascension, lat. 8° 45′ S., which is throughout the whole year within the S.E. trades, the mean rainfall for the two years 1854–55 was only 8·85 inches. At St Helena, which lies constantly within the same trades, five years give a mean rainfall of 5·36 inches on the coast; but in the same island at a height of 1763 feet the annual amount rises to 23·98 inches. Malden Island and some other islands in the Pacific, about long. 150° W., and for some distance on each side of the equator, have been pointed to by Scott as practically almost rainless, as is shown by their containing extensive guano deposits. These islands are situated somewhat similarly to Ascension with respect to the zone of calms. In Mauritius the annual rainfall on a mean of four years was 30 inches at Gros Cailloux, but at Cluny, only 16 miles distant, for the same four years it was 146 inches; in regard to which Meldrum remarks that at Cluny, which is in the vicinity of mountains and forests, in the south-east of the island, and thus directly exposed to the trade wind as it arrives from the sea, the rainfall in almost any month is from four to six times greater than at Gros Cailloux on the north-west coast, where neither mountain nor forest exists, and where the S.E. trade arrives considerably drained of its moisture.

From what has been said it is evident that the heaviest rains will be brought by the winds which have traversed the greatest extent of ocean within the tropics, and which accordingly of all ocean winds have the highest temperature and humidity. These conditions are most completely fulfilled during the summer months of the northern hemisphere by the winds which, commencing from near lat. 30° S., blow home on southern Asia as the well-known S.W. monsoon of these regions. Accordingly it is by the winds of this monsoon that a larger rainfall is distributed over a larger portion of the earth's surface than occurs anywhere else in any season, and this large rainfall is in many regions still farther greatly increased by the mountain ranges which lie across the path of the rain-bringing winds.

It is on these winds that the rainfall of India chiefly depends. Along the whole of the west coast from the

Gulf of Cambay southward, and on the Western Ghats, the rainfall is excessive The following are some of the more interesting annual means in inches beginning with Bombay and proceeding southwards —Bombay, 74, Matheram, 247, Mahabaleshwar, 252, Ratnagiri, 104, Baura, 255, Goa, 102, Karwar, 115, Honawar, 139, Mangalore, 134, Cannanore, 132, Calicut, 116, and Cochin, 114 In the west of Ceylon the rainfall is also heavy, being at Colombo 87, at Galle 91, and at Ratnapura, at some distance inland among the hills, 149 Since the S W monsoon is drained of much of its moisture in crossing these mountains, a greatly diminished rainfall is distributed over the interior and east side of India, and on the eastern slopes of Ceylon

If now we cross to the eastern shores of the Bay of Bengal, we again encounter an excessive rainfall along these coasts and up the slopes of the mountains looking down on them Thus from south northward the following are among the more characteristic rainfalls in inches —Nancowry, 102, Port Blair, 116, Mergui, 152, Tavoy, 196, Maulmain, 189, Rangoon, 100, Bassein, 98, Sandoway, 212, Akyab, 198, and Chittagong 104 On the other hand, at Thyetmio, inland on the Irawadi, the annual rainfall is only 48 inches

We have shown how, in accordance with the peculiar distribution of pressure in India in summer, the monsoon is diverted up the valley of the Ganges as an E S E wind, distributing on its way, even to the head of the valley, in a generous rainfall the moisture it has brought from the Indian Ocean and the Bay of Bengal The rainfall does not extend farther westward than the basin of the Ganges, and the precipitation is most copious along the lower Himalayas, the largest falls being recorded at heights about 4000 feet,—being, as pointed out by Hill, near the level at which the summer monsoon is cooled just below its dew point The following are some of the larger rainfalls in inches, beginning with the more western —Mussooree, 95, Naini Tal, 92, Khatmandu, 57, Darjiling, 121 Kurseong, 154, Buxa, 219, Kuch Behar, 131

The rainfall is very large in the north east angle of the Bay of Bengal and thence northwards towards Bhutan, or at the angle where the summer monsoon from the bay curves round to a westerly course on its way up the Ganges Thus at Noakhally, on the coast, it amounts in inches to 109, at Tura, on the Brahmaputra, immediately to west of the Garo Hills, 129, at Silchar and Sylhet to eastward, 117 and 155, whilst at Cherrapunji, on the Khasi Hills, it rises to 493 19 inches on a mean of twenty four years This last rainfall is the largest known on the globe, the causes of which are the highly saturated state of the monsoon on its arrival at the lower Ganges, the high mountain range of Burmah to eastward of Bengal, which turns the monsoon to the north, and the protrusion westwards of the Khasi and Garo Hills so as to lie in the line of that branch of the monsoon which passes from the lower Ganges into the basin of the Brahmaputra above Goalpara The consequence is that the highly saturated air of the monsoon in its passage across the Khasi Hills is suddenly raised to a height of about 6000 feet, and being thereby reduced far below the point of saturation the superabundant moisture is precipitated in unequalled deluges of rain The amount of the annual rainfall at all these places is determined, essentially if not altogether, by the rains of the summer monsoon, the relative intensity of which over India may be taken to be fairly represented by the rainfall of July

The rains which accompany the N E monsoon of the winter months may be represented by the rainfall for January These are heaviest in Ceylon, especially on its east slopes, and in southern India, or where the N E monsoon arrives after having traversed a large extent of ocean The fall for the month exceeds 6 inches over a large portion of the east coast, whilst at Colombo in the west the rainfall is only half that amount, and farther north at Pattalum the January rainfall is only 1 82 inches In southern India the amount varies from about 1 to 2 inches Blanford pointed out in 1873 (*Phil Trans*, vol clxiv p 618) that, while the surface winds of northern India in winter are northerly, on the Himalayas, especially the north west portion, southerly winds prevail during the cold months It is these upper southerly winds which bring the winter rains to the Punjab, Upper India, and the highlands of Assam It is further to be noted that winter rains also occur in Central India, where the prevailing surface winds are from east and north east The mean rainfall of January at Mussooree is 2 00 inches and at Naini Tal 2 86 inches, and in Assam, at Sibsagar, 1 13 inch Over a large tract of the east side of southern India from Nellore southward, including Ceylon, the maximum rainfall for the year occurs in the months of October and November

Rainfall of the Malay Archipelago and Australia —Under the direction of the late Dr Bergsma, systematic observations of the rainfall of the Malay archipelago were begun in 1879, the number of stations being 150 The results of the first three years show that the mean annual rainfall over the archipelago varies from about 60 inches in Timor to upwards of 200 inches at some spots among the western slopes of Sumatra But the most important feature in the rainfall in its relations to climate is not the absolute amount that falls annually, but rather the manner of its distribution through the months of the year Over the greater number of the islands rain falls copiously every month but as regards some of the islands the year is divided into dry and wet seasons as marked as are seen in the climates of India The key to this essential difference among the climates is the distribution of atmospheric pressure during the months of the year from south eastern Asia to Australia with the resulting prevailing winds During the winter months atmospheric pressure is high in south eastern Asia and low in the interior of Australia, the difference being about three quarters of an inch Since between these two regions the fall in the mean pressure is practically uninterrupted the Malay archipelago lying between them is swept by northerly winds (fig 14) As these winds have traversed a great breadth of ocean in their course they arrive in a highly saturated state, and consequently deposit a copious rainfall particularly on the northern slopes of the higher islands Hence in these months the rainfall over the islands without exception is large, the mean monthly amount being in many cases more than 30 inches These winds continue their course to southward towards the low pressure region in the interior of Australia and deposit along the north coasts of that continent a monthly rainfall rising generally to from 14 to 20 inches On advancing into the interior, the mean amount gradually diminishes at the successive telegraphic stations to 3 50 inches at Alice Springs near the tropic of Capricorn The amount of the rainfall for any particular year and the distance from the coast to which the rains penetrate inland, depend essentially on the height of the winter pressure of south eastern Asia as compared with the low mean pressure of central Australia, by which the strength of the northerly monsoon is regulated

On the other hand during the summer of the northern hemisphere pressure is high in the interior of Australia and low in China the mean difference being about half an inch Between the two regions the fall in the mean pressure is continuous and uninterrupted and as a consequence southerly winds prevail over the intervening archipelago These winds, as they advance from the continent into lower latitudes, are absolutely rainless in the north of Australia and over Timor and the other Malay islands which are separated from Australia only by a comparatively narrow belt of sea During the three years no rain whatever fell in Timor in July and August and the fall in June, September, and October was small As however the winds pursue their course to northward they eagerly lick up moisture from the sea so that by the time they arrive at Amboyna they have become so saturated that the monthly rainfall there rises to nearly 30 inches Again at some distance to the west of Timor rain falls more or less regularly every month, the amount increasing in proportion to the extent of ocean traversed by the S E winds, which advance towards these islands from the direction of Australia These marked differences among the climates of the Malay archipelago which, since they really depend on the geographical distribution of land and sea of this part of the globe, must be regarded as permanent differences, have played no inconspicuous part in the singular distribution of animal and vegetable life which characterizes the archipelago

May in Scotland north of the Grampians, June in Orkney, Shetland, Iceland, the west of Ireland, and the north-west of France, and July over the whole of the south of Europe The driest month occurs nowhere in Europe in any of the five months from August to December

Rainfall of North America —West of the Rocky Mountains the rainfall is very unequally distributed, the annual amounts varying from 86 inches at Astoria, near the mouth of the Columbia river, to 8 inches at San Diego on the coast, and 3 inches at the head of the Gulf of California. Over the whole of the region between the Cascade and Rocky Mountains the rainfall at all seasons is extremely small, this being indeed that feature in the climate to which the formation of the cañons of that region is chiefly to be referred On the other hand, in the United States and Canada to east of long 100° W the distinguishing feature of the rainfall is the comparative equableness of its distribution, an annual rainfall exceeding 50 inches occurring only over restricted districts, and a rainfall as low as 20 inches being scarcely met with anywhere The regions where the rainfall exceeds 50 inches are Florida, the lower basin of the Mississippi, and the Atlantic seaboards of Nova Scotia and Newfoundland

In January the annual maximum rainfall occurs over the whole of the west coast from Sitka to lower California, but in the interior between long 120° and 95° W the amount is everywhere small, and over a considerable part in the south west of this region no rain falls The region of largest rainfall extends from Louisiana to West Virginia, where the mean varies from 4 to 6 inches Over nearly the whole of the Dominion of Canada, by much the greater part of the winter precipitation is in the form of snow, which has been carefully measured and recorded by the Meteorological Service The average snowfall for January exceeds 30 inches at St John s, Newfoundland, in Anticosti, Prince Edward Island, and in many other regions

In July the rainfall is everywhere small in the west, a large part of this extensive region being absolutely rainless The remarkable dryness of the climate at this season is due to the N W winds that set in towards the low pressure of the interior, which thus blow towards warmer regions The rainfall to the east of the Rocky Mountains is distributed by the winds which are connected with the low pressure region of the interior and with the high pressure region of the Atlantic The result is two regions of larger rainfall, the one in the south east of the States and the other to the west of the lakes The summer winds of the south eastern coasts are southerly, and as they are anticyclonic in their origin and have in their course traversed some extent of ocean, they arrive well but not super saturated, and pour down a rainfall in July of 6 inches and upwards along the coasts and for some distance inland from Louisiana to Chesapeake Bay Further, since in July these winds attain their maximum force and persistency, the rainfall at the same time reaches the maximum along the whole coast from Boston to some distance west of New Orleans Since the summer winds blow in the line of the Alleghany mountains and not across them, the rainfall diminishes in ascending their slopes The comparative equableness of the rainfall over the eastern States is the necessary result of the winds passing into higher latitudes, and, therefore, cooler regions A broad region where the rainfall is less than on each side of it, extends from Michigan to the south west as far as Canadian River To the west of the lakes the rainfall rises above 4 inches, and, since over this region the winds become somewhat easterly as they flow towards the low pressure area, it is probable that the larger rainfall of this prairie region has its origin in no small degree in the evaporation of the lakes On ascending the higher reaches of the Mississippi, the amount diminishes, but scarcely falls lower than 2 inches, being thus analogous to the summer rains of the Upper Ganges On crossing the water parting into the basin which drains into Hudson Bay, we encounter E and N E winds laden with vapour licked up in their passage over Hudson s Bay, which they distribute in a generous rainfall of probably 3 to 5 inches over the rising colonies of Manitoba and Saskatchewan An important point in the climate of the States is that over nearly the whole of the extensive region stretching between Alleghanies and Rocky Mountains, except the south coast already referred to, the annual maximum rainfall does not occur in summer but in spring, the month of largest rainfall in the great majority of cases being May In the basin of Hudson s Bay July is the month of largest rainfall

Rainfall of Central and South America —The following are, in inches, the larger and more interesting annual rainfalls round the coasts —Vera Cruz, 182, Belize, 75, Maracaibo, 163, Caracas, 155, Georgetown, 95, Paramaribo, 142, Cayenne, 140, Para, 71, Pernambuco, 109, Buenos Ayres, 34, Bahia Blanca, 19, Puerto Montt, 102, Valdivia, 109, Valparaiso, 100, Serena, 93, Lima, 9, and a large part of Peru, nil A remarkable feature of the rainfall of South America is the large amounts that fall in the basins of the Orinoco and Amazon, the fall is 91 inches in the upper basin of the Madeira, and 112 inches at Yqutos (lat 3° 40′ S, long 72° 57′ W) The reason is that this immense region, where pressure appears to be almost constantly low, is open to the highly saturated winds that blow from the equatorial Atlantic. Quite different is the distribution of the rainfall over the La Plata basin The annual falls, in inches, are 92 at Joinville, 58 at Corrientes, 44 at Monte Video, 36 at Parana, 24 at Santiago, 22 at San Luis, and only 6 at Mendoza The fall rapidly rises in ascending the eastern slopes of the Brazil mountains facing the South Atlantic, thus, while the amount at Rio Janeiro is 45 inches, on the hills to northward it is 116 inches

In January northerly winds prevail on the south coasts of the Gulf of Mexico and the Caribbean Sea, and as they have their origin in the high pressure of the American continent, and in crossing the sea pass into lower latitudes, the January rainfall of these coasts is comparatively small In July, however, the prevailing winds are easterly, and as they have traversed a large extent of the equatorial waters of the Atlantic they are highly saturated, and consequently the July rainfall of these coasts is everywhere very large The following are, in inches, the January and July rainfalls —Caracas, 1 00 and 14 04, Guatemala, 0 28 and 10 79, Vera Cruz, 5 10 and 35 90 The seasonal distribution of the rainfall in the basin of the Amazon is the reverse of this In January the position of the belt of calms is about lat 3 N, and as pressure is relatively low over the basin of the Amazon, especially its southern slopes, the trades and the west portion of the region of calms unitedly spread their highly saturated air over the whole region as far as the Andes, resulting in one of the most widespread heavy rainfalls anywhere to be met with On the other hand, since in July the belt of calms is about lat 10° N, the saturated atmosphere of the tropical regions no longer flows up the Amazon, but is carried westward into the Caribbean Sea and Gulf of Mexico Hence at this season the rainfall of the Amazon valley is small The following are, in inches, the January and July falls —Para, 6 51 and 3 26, Manaos 7 33 and 1 82, upper Madeira, 15 90 and 0 30, and Yquitos, 10 24 and 4 26 On the La Plata in January pressure is low, and as winds consequently blow from the ocean in upon the region of low pressure the rainfall is large, but as pressure is high in the interior in July the rainfall in that month is small The following are in inches the January and July rainfalls —Buenos Ayres, 2 37 and 1 70 Parana, 4 63 and 1 32, Corrientes, 5 24 and 2 67, Joinville, 14 26 and 3 55, and San Luis, 2 63 and 0 00

Rainfall of Africa —As regards the rainfall, Africa presents the greatest diversity in its climates The following are the annual amounts in inches at various points on or near the coast —Port Said, 2, Alexandria, 8, Tunis, 12, Algiers 31, Oran, 17, Mogador, 50, mouth of the Senegal 17, Goree, 21, Sierra Leone, 126, Christiansborg, 23, St Thomas, 40, Gaboon, 106, Loanda, 11; Cape Town, 23, Mossel Bay, 12 Port Elizabeth, 24, Durban, 43, Zanzibar, 58, and mouth of the Zambezi, 61 In the north of the continent, the rainfall rapidly diminishes inland, and over the great desert of Sahara practically none falls In the interior of Algiers it diminishes, the amount at Laghouat being 17 inches, and at Biskra 9 In Egypt the rainfall is limited to a narrow strip along the coast, at Cairo the annual fall scarcely amounts to an inch. The January and July rainfalls are, in inches, as follows —Port Said, 0 46 and 0 00, Alexandria, 1 95 and 0 20, Algiers, 4 43 and 0 04, Biskra, 0 56 and 0 03, St Louis (Senegal), 0 28 and 3 00, Goree, 0 00 and 4 06, Sierra Leone, 0 69 and 24 20, Christiansborg, 0 50 and 2 00, Katunga, 0 11 and 4 76, Gaboon, 9 35 and 0 48, Cape Town, 0 28 and 3 83, Durban, 5 00 and 1 70 Pretoria, 6 07 and 0 71, and Zanzibar, 2 02 and 2 35 At Zanzibar the heaviest rains occur about the equinoxes the mean for April being 14 55 inches, and for October 6 80 inches

In the case of this, as the other continents, the explanation of the different amounts is to be had in the seasonal changes of wind In the north the winter rains are to a very large extent the accompaniment of the Mediterranean storms of that season but in summer pressure is diminished in the interior and increased in the Atlantic to the north west, resulting in strong steady northerly winds, which as they advance into hotter regions are unaccompanied with rain. The heavy summer rains from Senegambia to the Gold Coast are due to the strong monsoonal winds which set in towards the interior, thus drawing over these coasts the highly saturated air of the belt of calms and of the trades immediately to the north and south of it Since in winter the belt of calms is removed 8° of latitude farther to the south, and the temperature of the interior is greatly reduced, it follows that the winds blowing on these coasts from the sea are drier and less strong and consequently the rainfall is small At Sierre Leone the absolutely driest month is February, 0 31 inch, and the wettest September, 29 15 inches On the other hand, at Gaboon (lat 0° 25 N) the dry season is from June to August, when the belt of calms is farthest to the north, and the absolutely rainiest about the equinoxes, the mean of March being 14 70 inches and October 19 52 inches At Loanda (lat 8° 49′ S) the annual amount is only a tenth of what falls at Gaboon, and it falls wholly during the summer months of the southern hemisphere In South Africa pressure in January is lowest in the interior, towards which prevailing winds from the ocean blow, and as these advance into regions becoming rapidly hotter the rainfall all round the coast and for some distance inland falls to the annual minimum But in more strictly inland districts which are at a considerable elevation the rainfall reaches the maximum at the same season Thus the amounts in inches for January and July are—for Pretoria, 6 07 and 0 71 Maritzburg 4 23 and 0 21 Graham's Town, 2 89 and 1 51 Lower Nels Poort, 1 33 and 0 49, and Aliwal North, 1 [illegible] and 0 00 In the winter months pressure in the interior is high and the rainfall consequently small Though on the coast winds from the arid interior frequently prevail, yet the storms that sweep eastward past South Africa precipitate over large portions of the southern slopes of this part of the globe what must in the main be regarded as a generous rainfall It follows that the climates of these important colonies range themselves into two perfectly distinct classes —the climates of the inland regions and the Natal coast where the rains occur during the hottest months and the climates of the other regions where the annual rains occur during the coldest months Little is accurately known regarding the rainfall of the interior of Africa It is certain however, that it is small or nil over the extensive region of the Sahara and that it is large from about 15° N lat to some distance south of the equator Probably the rainiest part of Africa is the region extending from the Victoria Nyanza northwards to and including the gathering grounds of the two great tributaries of the Nile

Snow —Snow takes the place of rain when the temperature is sufficiently low to freeze the condensed moisture in the atmosphere Snow is composed of crystals, either six pointed stars or hexagonal plates, which exhibit the greatest variety of beautiful forms, one thousand different kinds having been observed These numerous forms Scoresby reduced to five principal varieties —(1) thin plates, comprising several hundred forms of the most exquisite beauty, (2) a nucleus or plane figure, studded with needle shaped crystals, (3) six sided, more rarely three sided, crystals, (4) pyramids of six sides, (5) prismatic crystals, having at the ends and middle thin plates perpendicular to their length In the same snowfall the forms of the crystals are generally similar The flakes vary from 0 07 inch to an inch in diameter, the smallest occurring with low temperatures and the largest when the temperature approaches 32° If the temperature is a little higher, the snow flakes are partially thawed in falling through it, and fall as sleet The white colour of snow is caused by the combination of the different prismatic colours of the minute snow crystals The density of snow is far from uniform, it is generally from ten to twelve times lighter than an equal bulk of water, but varies from eight to sixteen times lighter than water

The limit of the fall of snow near sea level coincides roughly with the winter isothermal of 52 , since in places where the mean winter temperature is no higher than 52 that of the air falls occasionally to 32 or lower during the winter months As regards Europe, the southern limit is about Gibraltar, in North America it is Savannah, New Orleans, the mouth of the Rio Grande, the head of the Gulf of California, and San Francisco In Europe, north of lat 60°, snow falls generally on an average of from 80 to 110 days in the year At Upsala the number of days is 61, at Warsaw 45, Aberdeen 42, Oxford 18, Ostend 15, Brussels 27, Tarum (in the south west of Jutland) 12, Copenhagen 23, Vienna 33, Odessa 19, Sebastopol 12, Milan 11, Trieste 6, Saragossa 5, Madrid 3, and Lisbon 1 In Greenland the number of days exceeds 80, and this figure is nearly reached in Newfoundland and the north east seaboard of Nova Scotia At Quebec the mean days of snow are 66, Halifax 64, Winnipeg 54, Detroit 34, Cape Henry 13 St Louis 11, mouth of the Columbia River 7, and Charleston, S C, 2 In Russia the time of the year when snow falls most frequently is December and January, except in the south of the empire, where February is the month of the most frequent occurrence of snow But to the north of a line drawn from the entrance of the Gulf of Finland through Warsaw, Cracow, Salzburg, and Santiago March is the month of maximum occurrence in the great majority of instances, while to the south of this line it is January and in several cases December

The largest falls of snow occur in the Antarctic regions, as is well attested by the magnificent icebergs of solidified snow which break off all round from the lofty walls of ice that engirdle the Southern Ocean Excepting perhaps in the Dominion of Canada, no data have been anywhere collected from which even a rough estimate could be formed as to the mean annual amount of snow that falls in different parts of the globe

Snow Line —The snow line marks the height below which all the snow that falls annually melts during summer No general rule can be stated for this height in different climates owing to the many causes determining it These are the exposure of mountain slope to the sun (and hence, other things being the same, it is higher on the south than on the north sides of mountains), exposure to the rain-bringing winds, the steepness of the mountains, and the degree of dryness of the air Hence the position of the snow line can be known by observation only It falls only little on either side of the equator to lat 20°, from lat 20 to 70 it falls equably, but from lat 70° to 78° much more rapidly To this general rule there are many exceptions It is 4000 feet higher on the north than the south side of the Himalayas, owing to the larger snowfall on the south, and the greater dryness of the climate of the north side, and therefore the greater evaporation from the snow there It is higher in the interior of continents than near the coasts, because the precipitation is less and summer heat greater In the Caucasus it is 11,063 feet high, but only 8950 in the Pyrenees In South America it rises from the equator to lat 18°, and more on the west than on the east slopes of the Cordilleras, owing to the large precipitation on the east and small precipitation and arid climate of the west side of that chain of mountains It is as high in lat 33° S as in 19° N, but south of that latitude it rapidly sinks owing to the heavy rains brought by the moist N W winds of these regions In the south of Chili it is 3000 feet lower than in the same latitudes in Europe, and 6000 feet lower than in the extremely arid climates of the Rocky Mountains

Storms —If weather charts representing a large part of the northern hemisphere be examined, two distinct systems of pressure are seen which change their forms and positions on the earth's surface from day to day The one set are systems of low pressure marked off by concentric isobars enclosing pressures successively lower till the centre is approached, and the other systems of high pressure marked off by concentric isobars enclosing pressures becoming successively higher towards the centre The former of these are called cyclones, and the latter anticyclones These areas of low pressure are the distinguishing characteristics of the hurricanes and typhoons of tropical regions, and of the ordinary storms of higher latitudes, and they may all be conveniently grouped under the general name of cyclones Fig 19 shows a storm which was passing across north western Europe on the morning of November 2, 1863, and it may be taken as fairly representing the general features of cyclones In the figure the arrows fly with the wind, and the force of the wind is indicated by the number of feathers on the arrows

It will be seen that the winds indicate, not a circular movement round the centre of lowest pressure, but a vorticose motion inwards upon that centre, the motion being opposite to that of watch hands In other words, the wind follows Buys Ballot's law, already explained The winds are strongest where the isobars are closest together, or they are generally proportioned to the "barometric gradient,"—a term introduced by Stevenson in 1867 Cyclones have diameters seldom less than 600, and they occasionally exceed 3000 miles, the cyclone of fig 19 had a diameter of about 1200 miles The cyclones of the Mediterranean are usually of smaller dimensions than those of north western Europe and America The rates at which cyclones advance over the earth's surface vary greatly, the average in America being 24 miles an hour, in the Atlantic 20 miles, and in Europe 26 miles A rate as high as 70 miles an hour has occurred in the British Islands, sometimes they remain stationary, and more rarely their course is for a time retrograde The temperature and humidity increase at those places towards and over which the front part of the storm is advancing, and fall at those places over which the front part of the storm has already passed In other words, the temperature and humidity rise as pressure falls and fall as pressure rises This is the important climatic significance of cyclones Thus a succession of low pressures passing eastwards in courses lying to northward of the British Islands are the essential conditions of open winters, whereas, if the cyclones follow courses lying to southward, the winters are severe In a cyclone the broadest feature of weather is an area of rain about or rather somewhat in front of the centre, surrounded by a ring of cloud, outside which the sky is clear The precise form and position of these areas have been shown by Abercrombie to vary with the type of pressure distribution, with the intensity of the cyclone, and with the rate of its progress, and they are also influenced by local, diurnal, and seasonal variations

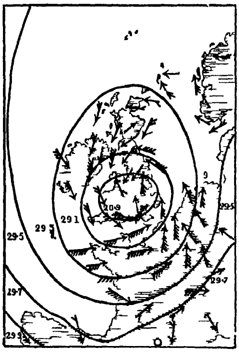


Fig 19

The chief point of difference between American and European storms is essentially the result of the mean winter pressures to the west and north west of their respective storm tracks Owing to the high winter pressure in the interior of America, the barometer rises in the wake of the storms of the United States more rapidly, the wind veers round more quickly and more uniformly to N W, N N W, and N and keeps longer in these directions, and the temperature and humidity fall to a greater degree, than happens in Europe In the New England States and Canada the easterly winds of the storms, coming as they do from the Atlantic, are disagreeably cold, damp, and misty in a degree and with a frequency much greater than occurs with the same winds in the British Islands

The chief points of difference between the hurricanes and typhoons of the tropics and the cyclones of higher latitudes are these —tropical cyclones are of smaller dimensions show steeper barometric gradients and therefore stronger winds, and advance at a slower rate over the earth's surface Another point of difference is that a large number of the hurricanes of the West Indies and the typhoons of eastern Asia first pursue a westerly course, which gradually becomes north westerly, and on arriving at about lat 30° they recurve and thereafter pursue a course to north east wards The tropical cyclones of the Indian Ocean south of the equator also first pursue a westerly course, which gradually changes to south west, and often on arriving about lat 30° recurve to the south east Many of the cyclones of India have their origin to westwards of the Nicobar Islands, pursue a course to north westward, and die out in the valley of the Ganges, and, similarly, a considerable number of the cyclones of the West Indies pursue a westerly course through the Gulf of Mexico, and several die out in the States

The most dreadful attendant on tropical cyclones is the storm wave, caused by the in blowing winds and the low pressure of the centre of the storm When this wave is unusually high and is hurled forward on a low lying coast at high water it becomes one of the most destructive agents known The Bakarganj cyclone of October 31, 1876, was accompanied by a wave which flooded the low grounds to the east of the delta of the Ganges to heights varying from 10 to 45 feet, by which more than 100,000 human beings perished

Tracks of Cyclones of North America, Atlantic, and Europe —In the *Physical Atlas of the Atlantic Ocean*, issued under the direction of Dr Neumayer of the Deutsche Seewarte, plate 28 shows by shadings the mean positions of the centres of cyclones and by lines their mean tracks The following are the regions where the lowest barometer or storms has been most frequently found —the region to west south west of the lakes of the United States, the Gulf of St Lawrence, mid Atlantic about lat 35° long 52°, to the south west of Greenland to the south west of Iceland, which is by far the most important of the whole, to the south west of the Lofoten Isles, the region embracing Denmark, the south of Scandinavia, and Finland and, as secondary centres of frequency, the south of the British Islands, Corsica and part of Italy adjoining, and the north east of the Adriatic The great importance of these centres where the lowest barometers are most frequently found, consists in the indication they give of the precise regions either where many storms originate or where they are either retarded or arrested in their course As regards the origin of storms, the centre west of the Mississippi is the region where most of the United States storms originate, the centre in the Gulf of St Lawrence is where many of the great Atlantic storms have their origin, and the centres in mid Atlantic and to the south west of Iceland are the regions where the storms of north western Europe chiefly originate The centres on the south west of Greenland, the Lofoten Isles, Denmark, and the south of the British Islands, all appear to suggest that storms are retarded in their onward courses on coming up against large masses of land,—which may, in part at least, be occasioned by the heavy rainfalls that mark these parts of their courses

Of all storm tracks the most frequently taken is that by the storms of the United States, which pursue an easterly course through the lakes to the Gulf of St Lawrence A considerable number of storms follow a course from Nova Scotia to Davis Straits, but the larger number take a north easterly course through the Atlantic towards Iceland and thence past the north of Norway Among the less frequent but important tracks are these —from near New Orleans along the east coast of the States towards Nova Scotia, from mid Atlantic to south of Ireland and thence through France to the north of the Mediterranean and from the Atlantic about lat 42° long 40° in a north easterly course quite outside but at no great distance from the British Islands, and thence towards the North Cape Of the tracks more immediately affecting British weather are one from Iceland in a south easterly direction through the North Sea and Germany, and four tracks which start from near Scilly —(1) to the south east as already described, (2) eastward through the north of Germany, (3) north east to Christiania, and (4) north through Ireland and the Hebrides These are the storm tracks which chiefly give the United Kingdom its easterly and northerly winds

The Inclination of Winds to the Isobars—The vorticose motion of the winds in a cyclone towards and in upon the centre has been already pointed out One of the more important practical problems of meteorology is the determination of the angle of inclination of the winds to the isobars in the different segments of the cyclone, not only from the application of the results of the inquiry to the theory of storms but also to practical navigation The first real contribution to the subject, based on accurate measurements, was made by Clement Ley in 1873[1] From the observations made at fifteen places in north west Europe examined by him he showed that the winds incline from districts of higher towards those of lower pressure at a mean angle of 20 51, that the inclination s much greater at inland than at well exposed stations on the coast, the respective angles being 28° 53 and 12° 49 , and that the greatest inclinations are with S F winds Then follow S W, N E, and N W winds, the last showing the least inclination Whipple has recently compared the winds at Kew with the barometric gradients for the five years ending 1879, with the result that the greatest inclination is 63° with S E winds, the least 35° with N E winds, and the mean for all winds 52°

As regards the open sea, Captain Toynbee has shown, from a careful investigation of the great Atlantic storm of August 24, 1873, that the mean angle of inclination calculated from one hundred and eight observations was 29°, the mean at the three selected epochs examined varying from 25° to 31°

Barometric Gradient and Velocity of the Wind—In inquiring into the relation of the velocity of the wind to the barometric gradient, it is necessary to have some definite information as to the increase of the velocity with height above the ground Stevenson recently made observations on this point on winds varying from 2 to 44 miles an hour from the surface up to a height of 50 feet, from which he has drawn the following conclusions —(1) the spaces passed over in the same time by the wind increase with height above the ground, (2) the curves traced out by these variations of velocity from 15 to 50 feet high coincide most nearly with parabolas (fig 20) having their vertices in a horizontal line 72 feet below the surface, (3) between 15 feet and the ground there is great disturbance of the currents, so that the symmetry of the curves is destroyed, (4) the parameters of these parabolas increase directly in the ratio of the squares of the velocities of the different gales If x be the velocity of the wind at height H above the ground, the parameter of the corresponding parabola is $x^2/(H+72)$, and as x varies the parameter will vary as x^2 or as the square of the velocity of the gale It follows that, to render wind observations comparable, it is necessary that anemometers be placed at one uniform height above the ground, and that standard height not lower than 15 feet above the surface It is very desirable that the inquiry were prosecuted up to a height of 100 feet, and it is of the utmost importance that the variation in the diurnal velocity be at the same time determined at different heights from 15 feet upwards

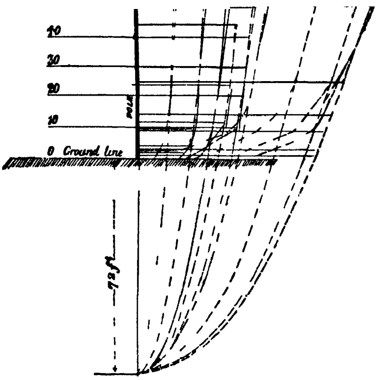


Fig 20

Stevenson also made wind observations on the Calton Hill, Arthur s Seat, and the Pentland Hills, in the vicinity of Edinburgh, up to a height of 1600 feet above sea level It is from observations made at stations on knolls and peaks at different heights above the sea, and at different heights above the surfaces of their summits, that the problem of the variation of the wind's velocity at different heights with the same barometric gradient can be ascertained In carrying the inquiry to considerable heights, the results cease to be comparable with those obtained at lower levels, unless in those cases where neighbouring heights are available for data from which the barometric gradient at the observed height can be calculated The results of observations as to the velocity of atmospheric currents at very great elevations in the atmosphere deduced from the apparent movements of the higher clouds are altogether incomparable with the winds near the surface of the earth, for these among other reasons —the heights of the clouds can be at best but imperfectly ascertained, the motion of the clouds, particularly the higher clouds, may be only apparent, it being sometimes difficult to distinguish between the formation and dissolution of clouds and their motion, and above all, since the higher clouds are usually the accompaniments of the greater weather changes, their movements are the result of barometric gradients towards a knowledge of which we are absolutely powerless to take a single step

As regards surface winds, Clement Ley in 1881, and Whipple more recently and with greater fulness, have calculated the mean wind velocities for twelve gradients,—the gradients being derived from the daily weather charts of the Meteorological Office for the five years 1875 to 1879 at 8 A M, and the corresponding wind data being obtained from the hourly readings of the Kew anemograph The barometric gradient is for 15 nautical miles, and the following are the velocities for the twelve gradients on the mean of the year —

Gradient inch	Velocity miles	Gradient inch	Velocity miles
0 002	5 0	0 017	15 0
0 005	7 0	0 020	16 5
0 007	7 5	0 022	19 1
0 010	9 2	0 025	22 0
0 012	11 6	0 027	22 0
0 015	12 6	0 030	25 5

The influence of season is very strongly marked The velocities for the same gradients in order are—October to December, 12 5 miles, July to September, 12 6 miles, January to March, 14 8 miles, and April to June, 17 2 miles From those observations of Whipple it follows that during the six months when the temperature is falling the velocity for the same gradients is least, while the velocity is greatest during the six months when the temperature is rising, and absolutely greatest during the three months ending June, when the greater part of the annual increase of temperature occurs It is evident that the observed increase in the velocity of the wind for the same gradients is to be referred to the same cause that brings about the diurnal increase in the wind s velocity, viz. the wind blowing over a warmer surface than itself

---

[1] *Journal Scottish Meteorological Society*, vol iv p 66

Whipple has also sorted the winds according to the eight points of the compass, with results of the greatest interest If N W, N, N E, and E winds be grouped together as polar, and S E, S, S W, and W winds as equatorial winds, the mean hourly velocity of the polar winds, for the same gradients, is 1 1 miles in excess of the equatorial winds Now, since polar winds pass into lower latitudes, the surface of the earth over which they blow is warmer, whereas the surface is colder than the equatorial winds which blow over it It follows that the increased velocity of polar winds is referable to the same conditions which result in the diurnal increase in the wind's velocity and the greater velocity for the same gradients of winds when the annual temperature is rising, since in all these cases the winds blow over a surface of a higher temperature than their own

It is evident from these considerations that for the development of the law of the relation of the wind's velocity to the barometric gradient with an exactness sufficient to warrant us in expressing that relation in a general mathematical formula much yet remains to be done In truth, as regards the various formulæ submitted by Ferrel, Mohn, Hann, Everett, and others, we have no choice but to allow the justness of Strachan's criticism (*Modern Meteorology*, p 98) that the theoretical values furnished by the formulæ do not accord with the actual values, and that therefore a satisfactory formula is yet to be found Ere such a formula need be looked for, the conditions must be fulfilled for the preliminary work of supplying the observational data required The "Challenger" observations prove that, with gradients substantially the same, the velocity of the wind is greater on the open sea than near land, and we have seen that the velocity varies with the hour of the day, and generally is increased as the temperature of the surface rises above that of the air blowing over it, and diminished as the temperature of the surface falls below that of the air It is evident that observations on the open sea will afford data for the simplest solution of the problem, but on land the diurnal, seasonal, and non periodic changes of temperature greatly complicate the problem, and render necessary for its solution observations specially designed for the purpose It is not easy to see how these can be obtained but by carrying out the plan proposed in 1875 by Stevenson of establishing strings of well equipped meteorological stations planted sufficiently close that the barometric gradients may be determined within the limits of accuracy required Observations made twelve times daily for a year, at stations so arranged, would supply the observational data for the solution of this fundamental problem in meteorology Till some such proposal be carried out, the problem remains unsolved, for barometric gradients based on the widely separated existing stations are too uncertain and rough and the wind observations are wanting in that comparability which alone can satisfy the inquiry

Weather and Weather Maps—Weather is the state of the air at any time as respects heat, moisture, wind, rain, cloud, and electricity, and a change of weather implies a change in one or more of these conditions Of th changes the most important as regards human interests are those which refer to temperature, wind, and rain, and, as these are intimately bound up with the distribution of atmospheric pressure, the latter truly furnishes the key to weather changes

These relations are well shown by the International Monthly Weather Maps issued by the United States Signal Service Of these that for December 1878 is a striking example This month was characterized over the globe by unusually abnormal weather A line drawn from Texas to Newfoundland, across the Atlantic, the north of France, and Germany, thence round to south east, through the Black Sea, the Caucasus, India, the East India Islands, and Australia to the South Island of New Zealand, passes through a broad and extended region where pressure was throughout considerably below the mean of December, and this low pressure still further deepened in various regions along the line Another line passing from Australia, through the Philippine Islands, Japan, Manchuria, Behring s Strait, and Alaska, also marks out an extensive region where pressure was uninterruptedly below the mean

On the other hand, pressure was above the average, and generally largely so, over the United States to west of longitude 90°, over Greenland, Iceland, the Faroes, Shetland, and a large portion of the Old Continent bounded by a line drawn from Lapland round by Lake Balkhash, Canton, Peking to the upper reaches of the Lena Another area of high pressure extended from Syria, through Egypt and East Africa, to the Cape, and part of a third area of high pressure appeared in the North Island of New Zealand As regards North America, the greatest excess of pressure 0 196 inch above the mean, occurred in the Columbia Valley, from which it gradually fell on proceeding eastward to a defect from the average of 0 146 inch near Lake Champlain and to northward, rising again to near the mean on the north of Nova Scotia To the north and north east exceedingly high pressures for these regions and the season prevailed, being 0 635 inch above the mean in Iceland, 0 500 in the south of Greenland, and at the three stations in West Greenland, proceeding northward, 0 445, 0 402, and 0 346 inch

West Greenland being thus on the west side of the region of high pressure which occupied the northern part of the Atlantic, and on the north east side of the area of low pressure in the States and Canada, strong south winds set in over that coast, and the temperature at the four Greenland stations, proceeding from south to north, rose to 1° 1, 8° 8, 12° 1, and 14° 4 above the means As the centre of lowest pressure was in the valley of the St Lawrence about Montreal, strong northerly and westerly winds predominated to westward and southward, where consequently temperature was below the average, the deficiency at Chicago and St Louis being 9° 5, and winds being easterly and northerly in California, the temperature there was also under the mean On the other hand, in the New England States, the greater part of the Dominion of Canada, and West Greenland temperature was above the average Pressure was much higher at St Michael s, Alaska, than to south westward at St Paul s, Behring s Strait, and hence, while temperature at St Paul s was 2° 9 below the normal, it was 12 0 above it at St Michael s, where strongly southerly winds ruled With these strong contrasts of pressure, America presented contrasts at least as striking in the distribution of the temperature Along the south of Lake Michigan the November temperature was 13° 7 above the normal, whilst the December temperature was 9° 5 below it, the difference there between the two consecutive months being thus 23° 2

As regards Europe, Iceland was on the east side of the patch of high pressure which overspread the north of the Atlantic, and hence northerly winds prevailed there and temperature fell 7° 2 below the mean, presenting thus a marked contrast to the high temperature of West Greenland at the time In Europe the area of lowest pressure occupied the southern shores of the North Sea, extending thence, though in a less pronounced form to south eastward Hence over the whole of western Europe winds were N E, N, and in the south west of Europe W, and hence everywhere from the North Cape to the north of Italy temperature was below the normal, in some places greatly so, the deficiency being 10° 4 in the south of Norway and 12° 2 in the south of Scotland On the other hand, on the east side of this area of low pressure winds were southerly and temperature consequently high In some localities in Russia the excess above the mean was 15° 0, and over a large proportion of European Russia the excess was not less than 9° 0 This region of high temperature extended eastward into Siberia as far as the Irtish, being coterminous with the western half of the anticyclonic region of high pressure which overspread central Siberia But over the eastern portion of the anticyclone northerly winds prevailed, with the inevitable accompaniment of low temperatures over the whole of Eastern Asia, the deficiency at Nertchinsk on the upper Amur being 6° 8 Here again, just as in America, Greenland, and Iceland, places with atmospheric pressure equally high presented the strongest contrasts of temperature Thus at Bogoslovsk, on the Ural Mountains, pressure was 0 211 inch and at Nertchinsk 0 154 inch above the normals but Bogoslovsk on the west side of the high pressure area had a temperature 15° 0 above, whilst at Nertchinsk it was 6° 8 below the average

At this time of the year the mean pressure falls to the minimum in Australia, but during December 1878 the usually low pressure was still further diminished Pressure at this season also falls to the annual minimum in the North Pacific and North Atlantic, and it has been seen that the low pressure of these regions was likewise still further diminished But in the case of the Atlantic it was attended with a most important difference The centre of lowest pressure, usually located to the south west of Iceland, was removed some hundreds of miles to the south east, and an unwonted development of extraordinarily high pressure appeared to the north ward overspreading the extensive region of Baffin s Bay, Greenland, Iceland Faroes and Shetland It was to this region of high pressure particularly in its relations to the low pressure region to the south east of it that the extreme severity of the weather in the British Islands at the time was due how this high pressure region was intimately connected with, and doubtless occasioned directly by upper atmospheric currents from the widely extended region of low pressure to southward with its large centres of still lower pressure in the North Sea, mid Atlantic and United States, where pressures were respectively 0 307 0 322 and 0 146 inch under the normals Thus with the single exception of the high pressure area about Greenland, the meteorological peculiarities which render December 1878 so memorable over nearly the whole globe arose out of a distribution of the earth s atmosphere essentially the same that obtains at that time of the year but the usual irregularities in the distribution of the pressure appeared in more pronounced characters

Taking the all important bearings of these areas of high and low pressure on weather and climate into consideration, along with the abnormal concentration of aqueous vapour over extensive regions which they imply, it is evident that, when the meteorologist will be in a position to forecast, on scientific grounds, the weather of the coming season for the British Islands, it is to the Atlantic he will require to look for the data on which the forecast is based

These questions, which the International Weather Maps of the United States enable us to discuss, are of the first importance in meteorology, whether we consider the amplitude of the atmospheric changes they disclose (these being often so vast as to embrace four continents at one time, besides being profoundly interesting from their direct bearings on the food supplies and commercial intercourse of nations) or regard the larger problems they present, with hints towards their solution, which underlie physical geography, climatology, and other branches of atmospheric physics The discussion presents the great atmospheric changes as influenced by oceans and continents, including the subordinate but important parts played by mountain ranges, extensive plateaus, and physically well defined river basins in determining the development, course, and termination of these changes

Weather Forecasts and Storm Warnings —It is in tropical and subtropical countries that an isolated observer may, with a close approximation to certainty, predict the approach of gales and hurricanes In these regions atmospheric pressure and the other meteorological conditions are so constant from day to day that any deviation, even a slight one, from the average of the hour and season in respect of pressure, the direction and strength of the wind, and the direction and amount of cloud, implies the presence of a storm at no great distance Dr Meldrum has practically worked out this problem at Mauritius with great success At the Royal Alfred Observatory there the mean pressure at sea level in January at 9 A M is 29 966 inches, from which it falls to 29 904 inches at 4 P M, then rises to 29 980 inches at 10 P M, and again falls to 29 927 at 4 A M The mean direction of the wind and the diurnal variation, both as regards direction and force, have been stated (p 125) Suppose then that the barometer is observed to fall after 9 A M more rapidly than is due to the usual daily barometric tide, that in the afternoon it does not indicate the second maximum or that it continues to fall instead of rising,—or suppose, in short, any deviation from the mean daily march,—then it is certain that there is somewhere an atmospherical disturbance near enough to Mauritius to influence the pressure The direction in which the disturbance is from Mauritius is readily known from the wind, and the distance of the storm closely approximated to by noting the rate and amount of the fall of the barometer, in connexion with the changes of the wind and the clouds,—the rate and progressive motion of the storm being known chiefly from the veerings of the wind For a good many years past notifications have been sent to the daily newspapers when observations show that a storm is not far from the island, stating its position and probable course from day to day The scheme of storm warnings at Mauritius has been entirely successful, and the result is of great value, since it shows what may be done at an isolated station in the ocean, or what may be done in ships at sea In this connexion it is not possible to overestimate the importance to seamen of a knowledge of the hourly variations of the barometer and its mean monthly heights over the ocean tracks of commerce

In passing from Mauritius to the British Islands we pass from a region where the forecasting of storms and weather is simplest and easiest to the region where it is most complex and difficult, particularly for the western districts of these islands The great difficulty lies in the fact that the British Islands are immediately bounded by the Atlantic to westwards, and, since practically every storm and nearly all weather changes come from that direction, no telegraphic communication of their approach can be received The Meteorological Office in London has therefore no choice but to base the forecasts on such of the observations telegraphed to the office as experience has shown to be the precursors of storms and other weather changes The more important of these observations are the falling and rising of the barometer taken in connexion with changes in the direction and force of the wind Since on the north side of the track of the centre of the storm winds are northerly and easterly and temperature low, and on the south side winds are southerly and westerly and temperature high, one of the most important points to be ascertained is the probable path the centre of the coming storm will take Though a good deal remains to be accomplished in the development of this phase of storms, yet much has recently been done in this direction by close examination of the changes of pressure in the region of the anticyclone contiguous to the advancing storm and by the changing positions of the rain area near the centre of the cyclone

As regards Europe, the facility of forecasting storms increases as distance from the west coasts is increased Thus to the middle and eastern districts of the British Islands, were a day and night watch established in the west, forecasts of almost every storm could be issued, the exceptions being those small cyclones or satellite cyclones, as they are called, originating within the British Islands themselves, which are frequently characterized at once by their severity and by the rapidity of their onward course In the United States, the system of weather forecasting is perhaps the best in temperate regions,—a result due to the admirable system organized and developed under the direction of the late General Myer, and adequately subsidized by the Government, but above all to the facilities to detect and track the storms in the region where nearly all of them have their origin, to west of the Mississippi, before they advance upon the more thickly peopled States

Meteorology sustained a heavy loss by the death in 1877 of Leverrier, who was not only the keenest-sighted of physicists but also the prince of organizers of systems of meteorological observation His last great service to the science was the establishment of a system of observation, by which the propagation of rain, hail, and other weather phenomena could be followed and recorded from commune to commune over France This scheme for the investigation of the vitally important bearing on the meteorology of a country of a comprehensive observation of its rainfall, hail, and thunderstorms, through numerous observers possessing sound local information, is not only eminently just in science, but is calculated to be attended with the greatest benefits to agricultural and other public interests The practical advantages of the scheme, it need scarcely be added, can only be reaped after a very large expenditure of labour and money in organizing a comprehensive parochial scheme of observation, systematically and persistently carried through and discussed

Further details regarding meteorological phenomena will be found in the articles **Atmosphere**, **Barometer**, **Climate**, **Hygrometry** **Ozone**, **Raingauge**, **Sea**, and **Thermometer.** (A B)

TERRESTRIAL MAGNETISM

1 In the preceding portion of this article some account has been given of the influence which the sun and moon exert upon the air, the earth, and the ocean, their strictly tidal effects being left to be separately dealt with The discussion of the influence of these bodies on what may be termed the movables of the earth will not be complete, however, without embracing an account of the changes which they produce in the earth s magnetism An account of the earlier magnetic observations has already been given under the heading Magnetism and our task will now be to give in the first place a description of the best and most recent instruments by which the magnetic state of the earth is determined embracing therein observatory instruments, those adapted for travellers whether by land or by sea, and differential magnetometers We shall next give a short account of the magnetic system of the earth and of its secular variation, and we shall then investigate the changes connected with terrestrial magnetism depending on the sun and moon In performing this task we shall be led to conclude that the sun s power is variable, and we shall therefore examine whether this conclusion is likewise borne out by strictly meteorological observations Finally we shall venture on remarks embodying a provisional working hypothesis, and our object will be gained if this should be found to suggest certain lines of thought to those interested in the subject which may lead them to examine and discuss the very great mass of observations at present existing

Instruments for Determining the Magnetic State of the Earth

(a) *Observatory Instruments*

2 *Declinometer* —It is that end of the needle which points to the north magnetic pole of the earth of which the position is invariably noted even when the observation is made in the southern hemisphere The difference of this position from true geographical north denotes what is called the variation or declination (east or west) of the needle East is often reckoned negative and west positive The instrument by which this information is obtained is called the declinometer The unifilar magnetometer, which is the form of declinometer now used, is described and figured in Magnetism, vol xv p 238

3 *Dip Circle* —The instrument by which the magnetic dip or inclination is observed contains a thin needle about 3 inches long the centre of gravity of which coincides as accurately as possible with the axis of motion of the needle The needle has two axles consisting of two very fine cylinders of hard steel standing at right angles to the plane of the needle and great attention must be paid to keep these axles in a state of perfect polish and dryness By means of these the needle can oscillate freely on two horizontal agate rounded edges, the one axle lying on the one edge and the other axle on the other If the centre of gravity coincides exactly with the axis of motion, and if there be no adhesion or friction between the axles and the agate edges the needle must settle into such a position that its magnetic axis lies in the true line of dip

The position of the ends of the needle is read by means of two microscopes which move round on a cross piece carrying verniers To view the position of the lower end of the needle we move round the lower microscope until the cross wire in its field of view (extending in the line between the two microscopes) symmetrically cuts the extremity of the needle The lower vernier is then read The same process is repeated for the upper vernier, and the mean of the two readings is taken This mean will accurately denote the position of the needle if the circle is properly set

The sources of error in a dip observation are—(1) a want of symmetry in mass, the centre of gravity of the needle not being coincident with the axis of motion, (2) the vertical circle being erroneously set, (3) a want of symmetry in magnetism, the magnetic axis not being coincident with the axis of figure, (4) excentricity, the axis of rotation of the needle not passing through the centre of the circle, (5) friction and adhesion of the axles as they rest on their agate supports This last source of error is guarded against by taking great care of the axles, and by inserting them gently into a piece of cork before each observation, the agate supports ought also to be rubbed with cork Then, again, when the needle has assumed its position, before reading it is gently raised by means of a lifter, the handle for turning which is shown in the figure towards the right It is then gently lowered, and this process is repeated until no apparent change of position is produced by the operation

4 We shall now describe a complete dip observation The first point is to make the needle to swing in the plane of the magnetic meridian In order to accomplish this, after levelling the instrument, the verniers are set for 90°, that is, for a vertical position of the needle The whole instrument is now turned round its horizontal circle until the extremities of the needle are bisected by the wires of the two microscopes, and the position of the vernier of the horizontal circle is then read The needle is next reversed so that the microscope shall view its other flat side, it is made vertical as before, and the position of the horizontal circle read once more Next the face of the instrument is turned round 180°, and the same two operations repeated We have thus four readings of the horizontal circle, and if we take the mean of these we shall have ascertained with sufficient accuracy the position of that plane for which the needle is vertical Now this plane must be removed 90° from the magnetic meridian, for in such a plane the horizontal magnetic force of the earth would have no resolved portion acting in the plane of the needle s motion, so that the needle would practically be under the sole influence of the vertical magnetic force, and would therefore point in a vertical direction By this means therefore we obtain the magnetic meridian, and thus know the plane in which we ought to swing the needle The needle must now be read in the following positions —(α face of instrument east—face of needle to face of instrument, (β) face of instrument west—face of needle to face of instrument, (γ) face of instrument west—back of needle to face of instrument, (δ) face of instrument east—back of needle to face of instrument Finally, the poles of the needle must be reversed, by rubbing them with powerful bar magnets in a direction opposite to that in which they were previously rubbed, and four observations taken corresponding to the above The mean of the eight observations so obtained will give us the true dip

The turning round of the face of the instrument from east to west is made to counteract any error due to erroneous setting of the vertical circle The reversal of the face of the needle is made to counteract any error due to the centre of gravity of the needle not being quite coincident in the direction of the needle s breadth with its axis of motion, and likewise any error due to want of symmetry of the magnetic axis The correction for excentricity is made by reading both ends of the needle Finally, the reversing of the poles of the needle is intended to counteract any error due to the centre of gravity of the needle not being coincident in the direction of the needle s length with its axis of motion

Dr Joule[1] has suggested a modification of the dip circle in which the needle is hung on fine threads on which it rolls instead of resting on agate supports

5 *Horizontal Force Magnetometer* —The theory of the instrument for determining the horizontal component of the earth s magnetic force has already been given in the article Magnetism, vol xv pp 238 *sq*, and the instrument is shown in two forms, *ibid*, figs 28 and 29 The corrections necessary for accurate results are explained in a paper by G M Whipple (*Proc Roy Soc*, 1877)

(β) *Instruments adapted for Travellers by Land*

6 *Declinometer* —For travellers by land the unifilar instrument .. 2), mounted on a tripod stand and duly levelled, is perhaps the most accurate kind of declinometer

For this purpose it is furnished with a transit mirror by means of which an image of the sun may be thrown into the field of view of the telescope, and—the geographical position of the station as well as the apparent time of the observation being known—an azimuth thus determined In order that such an observation may succeed, the following points must receive attention

In the first place the axis of the mirror must be horizontal the adjustment for this is made by means of a riding level Secondly, the normal to the plane of the mirror must be perpendicular to the axis The adjustment for this is made by a screw attached to the back of the mirror Take some object sufficiently elevated and reflect it into the telescope, getting the object bisected by the wire of the telescope Then reverse the mirror in its bearings If the object remains still bisected by the wire no correction requires to be made, but if not the screw at the back of the mirror must be moved until the object is in precisely the same position in both observations Thirdly, the line of collimation of the telescope must be perpendicular to the plane of the mirror In order to obtain this there is a collimating eye piece attached to the telescope by which the sun s light may be made to illuminate the cross wires Now turn the transit mirror until the reflexion of the illuminated cross wires coincides with the wires themselves, in which case the line of collimation of the telescope must be perpendicular to the plane of the mirror When this correction has been once made note the circle reading of a small vernier which moves with the mirror and always set the mirror so as to give this reading

---

[1] *Proc Lit and Phil Society, Manchester*, vol viii p 171

By these means an accurate reading of the sun's bearing may be made, and, the position of the place and the time of observation being known, there are tables which enable the azimuth to be at once determined

7 *Lloyd's Method of Determining the Total Force* —While the dip circle and the horizontal force magnetometer may be used by travellers in addition to their use as observatory instruments, the Rev Dr Lloyd has devised a new method of determining the total force The ordinary method of obtaining this is first to find the dip and the horizontal force from which the total force can be at once determined by the equation,—total force = horizontal force × secant dip This method is, however open to objection in high magnetic latitudes where the horizontal force is very small and the dip approaches 90° Now in Lloyd's method this objection is overcome Another circumstance which renders his method peculiarly convenient for high magnetic latitudes where a traveller's equipment must be kept as light as possible is the fact that it only requires the addition of two needles to an ordinary dip circle in order to give the required determination These needles must be carefully kept from contact with other magnets, and their poles never reversed

Here as before we have two unknown quantities to determine the one being the magnetic moment of the magnet and the other the total force of the earth We must therefore, obtain two results, the one embodying the product of the earth's total force into the magnetic moment of the needle, while the other gives the ratio between these two quantities

8 In order to determine the former of these let the needle have a grooved wheel of radius r attached to its axle as in fig 21 and over this wheel let an accurately known weight W suspended by means of a very fine silk thread The best way of doing this is to have a thread with two hooks of precisely equal weight at each end and then attach the preponderating weight W to one of these hooks When this is done a new position of equilibrium will be taken by the needle If we suppose that m denotes the magnetic moment of the needle that $\imath$ is the angle of dip at the place, and that η denotes the angle which the needle in its deflected position makes with the horizon the weighting being so made that η shall be less than $\imath$ then it is clear that the needle has been deflected out of its position of equilibrium through an angle $\imath - \eta$ If we call this angle u and designate by R the total force at the place, we obtain the following equation of equilibrium —

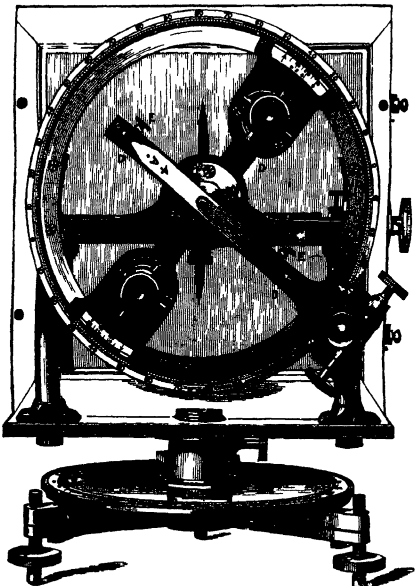


FIG 21 —Dip Circle

$$m\mathrm{R}\sin u = \mathrm{W}r \qquad (1)$$

on the supposition (which is very nearly but not strictly correct) that W denotes a constant force at all latitudes

9 Next, in order to determine the ratio between this needle's force and that of the earth, let it be removed and employed to deflect another substituted in its place

When using it thus as a deflector it should be laid in a frame in an invariable position as in fig 21 This frame is at right angles to the line between the two microscopes, and as both pieces move together the best plan is to turn the whole round until the deflected needle is visible in the centre of the field of the microscopes, in which position it is of course perpendicular to the deflecting needle By always keeping to this arrangement we secure an invariable distance between the poles of the two needles Suppose therefore that we have employed the needle as a deflector in the above manner, and that the deflected needle has thus been made to assume a position denoting an angle η with the horizon It has therefore been deflected from its position of equilibrium by an angle $\imath - \eta$ ($\imath$ denoting the dip as before) calling this angle of deflexion u, we obtain the following equation of equilibrium —

$$\mathrm{R}\sin u' = m\mathrm{U} \qquad (2),$$

U being a function depending upon the distance of the needles and on the distribution of free magnetism in them

10 If we multiply together equations (1) and (2), we obtain

$$\mathrm{R}^2\sin u\sin u = \mathrm{UW}r \qquad (3),$$

in which u, u are determined by observation, while W and r may be regarded as constants U is, as we have said a function depending upon the distance of the two needles and upon the distribution of free magnetism in them

The magnetic moment of these needles is of course liable to alteration, but if they are carefully guarded from contact with magnets we may imagine that while their intensity alters becoming weaker for instance, this nevertheless does not sensibly affect the distribution of the free magnetism within them, in which case the function U may be regarded as a constant quantity The results obtained by this method of Lloyd's fully confirm this hypothesis regarding U but it is essential that the two additional needles, the deflector and the deflected needle, should have their poles at no time either reversed or disturbed

Assuming therefore the constancy of the quantity U its value may be easily determined at any base station where the total force has been determined independently by the ordinary method

11 Having thus determined the value of U, or at once of UWr (which we may call c), let us carry our instrument to a different station and make the requisite observations We thus obtain

$$\mathrm{R} = \sqrt{\frac{c}{\sin u\sin u}} \quad . \qquad (4)$$

As this method is specially adapted for high latitudes the dip circle employed (fig 21) ought to be one for which the agate supports are horizontal so as to admit of the needle being visible when the dip is nearly equal to 90° It will also be noticed that, if the deflecting needle have the same temperature when it is used in equation (1) which it has when used in equation (2), then m in the one case is strictly equal to m in the other, and thus no temperature correction is rendered necessary

12 A slight modification of the method now described is sometimes adopted Instead of employing separate weights, which may be easily lost, two small holes are bored in the deflecting needle near each end The one of these is filled with a suitably heavy brass peg when the observations are to be made in the higher magnetic latitudes of the northern hemisphere, and the other is filled in a similar manner when the observations are to be made near the southern pole In this case therefore we must readjust the instrument as we pass from the one hemisphere to the other A slight change must be made in the formula when this method is adopted, for it is clear that the weight will not now act always at the same constant leverage If the weight be called W and its leverage when the needle is horizontal r, we shall have to modify equation (1) as follows —

$$m\mathrm{R}\sin u = \mathrm{W}r\cos\eta \quad . \; . \qquad (5)$$

Equation (2) will, however, remain unaltered, and hence equation (3) will become

$$\mathrm{R}^2\sin u\sin u' = \mathrm{UW}r\cos\eta \qquad (6).$$

If the quantity UWr be determined at the base station and called c, we shall have

$$\mathrm{R} = \sqrt{\frac{c\cos\eta}{\sin u\sin u'}} \quad . \quad . \quad . \qquad (7).$$

(γ) *Instruments adapted for Travellers by Sea*

13 *Azimuth Compass* —At sea the declination is generally observed by means of an azimuth compass invented by Kater This is exhibited in fig 22 It consists of a magnet with a graduated compass card attached to it At the side of the instrument opposite the eye there is a frame which projects upwards from the plane of the instrument in a nearly vertical direction, and this frame contains a wide rectangular slit cut into two parts by a wire extending lengthwise The eye piece is opposite this frame and the observer is supposed to point the instrument in such a

manner that the wire above mentioned shall bisect the sun's visible disk There is a totally reflecting glass prism which throws into the eye piece an image of the scale of the

must next read the division of the scale which is in the middle of the field of view He thus obtains a reading of the sun s position, let us call this 100° From this knowing the geographical position of his station and the time of the observation, he may deduce an azimuth, let us imagine that this is 70° W Thus a reading of 100° corresponds to a position 70° W Suppose next that the instrument is so adjusted that when the magnetic axis of the magnet is between the eye piece and the wire the reading is 0° It is thus clear that the magnetic meridian is 100° removed from the position 70° W Let us imagine that the instrument is so graduated that this denotes a position 30 E We have thus obtained the magnetic declination If the vessel be at rest the plan generally adopted is to take the reading of the sun when rising and also when setting a mean between the two will give that which corresponds to a geographical meridian

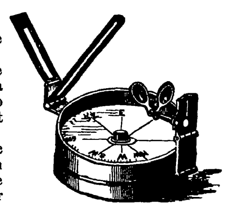


FIG 22 —Azimuth Compass

14 *Fox s Dip Circle* —This instrument contrived by Robert Were Fox is more especially useful for observations at sea In this case it must be placed on a gimball stand and duly levelled before commencing the observation The following are the peculiarities of this instrument —(1) the needles have two fine pivots or axles which are inserted into jewelled sockets (2 in order to avoid parallax there are two graduated circles the one farther from the eye than the other and when reading the needle the eye is to be so placed that precisely the same reading shall be given by both circles —the true position of the needle being thus obtained (3) the e is a rubber made of bone or ivory and roughened, the object of which is to rub a prolongation of the socket on the back of the instrument,—the friction which this rubbing causes enabling the needle to find its true position (4) to avoid as much as possible all effects due to friction and adhesion, the entire socket arrangement may be turned round The axles of the needle are thus compelled to be in contact with a different set of particles Another way of varying the suspension is to use a magnetic deflecting arrangement attached to the back of the apparatus Suppose that a reading of the position of the needle so deflected is now taken Next reverse the position of the deflecting arrangement, which is done by turning a movable circle attached to this arrangement 180° round let the position of the needle be again read On the hypothesis that the needle is equally deflected on opposite sides of its true position in these two observations, the mean reading will give the true dip The principle of the method of observing with this circle is precisely the same as that already described for observations on shore with an ordinary inclinometer

15 *Fox s Intensity Arrangement* is merely a modification of that introduced by Lloyd, and already described in § 7 [1]

(δ) *Differential Magnetometers and Self Recording Magnetographs*

16 In addition to determinations at fixed intervals of time, it is a point of much interest and importance to keep a continuous record of all the magnetic changes which take place at a few selected stations This is accomplished by means of differential magnetometers It is, however, necessary to continue to use absolute instruments side by side with differential magnetometers because the latter (with the exception of the declination instrument) are badly fitted for recording changes of long period, such as the secular changes of the horizontal and the vertical force The reason of this will presently be seen

17 Early in the history of such instruments it was found that hourly observations were exceedingly laborious and attempts were made to construct a set of self recording magnetometers The first set of such instruments which were brought into systematic operation were those devised and constructed by the late Charles Brooke which have been at continuous work in the Greenwich Observatory since 1848 In 1857 John Welsh devised a fresh set of self recording instruments, and introduced them into the Kew Observatory These, with certain slight modifications, have formed the type of instruments supplied to a large number of magnetic observatories all over the globe

18 As we cannot conveniently record changes of dip by a differential instrument, changes of vertical force are measured instead by a balance or vertical force magnetometer We have thus in a differential system whether adapted to eye observation or to continuous photographic registration three instruments, namely, the declination, the horizontal force and the vertical force magnetometers or magnetographs as the case may be The most recently constructed instruments are adapted both for photographic registration and for eye observation through a telescope The advantage of eye observations is that we see what is taking place at the very moment of its occurrence, whereas we only obtain the photographic record some time after the changes to which it relate have actually happened

We shall therefore describe—(α) the three instruments of the Kew pattern as adapted to eye observations (β) these instruments as adapted to continuous registration by photography (γ) the method of determining their scale coefficients, (δ) the method of determining the temperature coefficients of the force instruments

19 *Kew Instruments—Eye Observations* —Fig 23 shows us these instruments arranged in the relative positions recommended by Lloyd so as magnetically to interfere with one another as little as possible We are supposed to be viewing the whole from the south No 1 to the right is the declination instrument, No 2 that for the horizontal force, and No 3 in the distance behind the central pillar (No 4) the vertical force magnetometer Figs 24 25 26 give us the details of these three instruments in the same order as above Connected with each instrument there is a circular mirror or rather two semicircular mirrors, made of perfectly plane glass One semicircular half of each mirror is attached to the magnet and moves with it, while the other half is firmly attached to the marble slab Each magnet is enclosed in a gun metal case wit windows of perfectly plane glass, each gun metal case is covered with a glass shade and the whole is air tight and capable of exhaustion Each magnet too is provided with a copper damper with the view of checking its oscillations In fig 23 will be seen two pillars of smaller size The right hand pillar carries a telescope, with a scale attached, to record the position of the declination magnet The scale is reflected from the semicircular mirror moving with the magnet, and the position of this reflected scale as viewed in the telescope indicates the position of the magnet The optical arrangement for the other instruments is similar except that the vertical force mirror has a horizontal and not a vertical axis The telescopes for viewing the force instruments are attached to the left hand pillar of smaller size

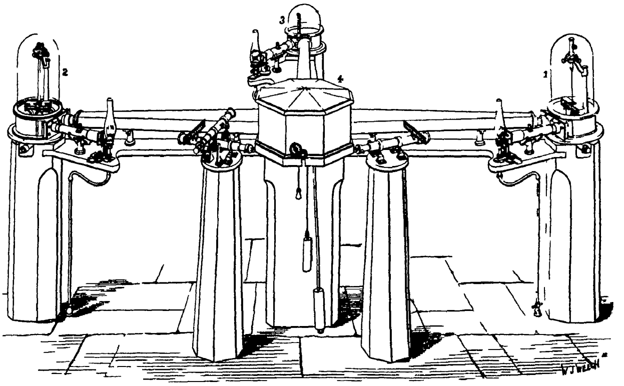


FIG 23 —Kew Instruments

20 The *Declinometer* [2] (fig 24) consists of a magnet about 5 inches long suspended by a silk thread freed from torsion as completely as

---

[1] A great deal of detailed information regarding instruments for absolute determination and the methods of observing with them is to be found in the *Admiralty Manual of Scientific Inquiry* in an article on Terrestrial Magnetism by Sabine and Welsh A treatise on *Terrestrial and Cosmical Magnetism* by E Walker, may likewise be consulted with much advantage

[2] For a detailed account of the Kew magnetographs, see *British Association Reports* 1859

possible To keep the state of the thread constant the glass shade should be rendered air tight, and should contain some substance for absorbing moisture, such as chloride of calcium It is clear that if the state of the thread remains the same and if the position of the magnetic axis of the magnet does not change this instrument should record faithfully the various changes of declination

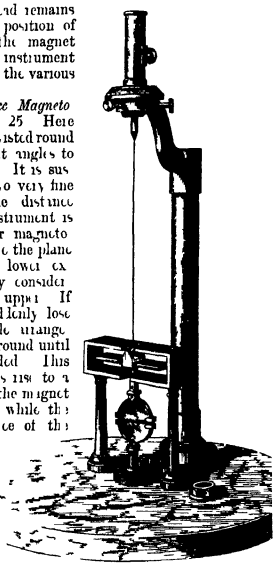


Fig 24 —Declinometer

The *Horizontal Force Magnetometer* is exhibited in fig 25 Here the magnet[1] has been twisted round into a position at right angles to the magnetic meridian It is suspended by means of two very fine steel wires some little distance apart, and thus the instrument is often called the bifilar magnetometer These wires have the plane passing through their lower extremities differing very considerably from that of their upper If the magnet should suddenly lose its magnetism the whole arrangement would be twisted round until the two planes coincided This difference of plane gives rise to a couple tending to twist the magnet round in one direction while the horizontal magnetic force of the earth constitutes an equal and opposite couple the two couples keeping the magnet in equilibrium The couple depending upon the bifilar arrangement may for the present be regarded as constant, that depending on the horizontal force of the earth is variable If the latter increase or diminish, the magnet will be slightly twisted round in one direction or the other

In the *Vertical Force Magnetometer* (fig 26), the magnet is balanced by means of a knife edge resting on an agate plane By means of two screws working horizontally and vertically the centre of gravity may be thrown to either side of the point of suspension, or it may be raised or lowered and the sensibility of the magnet when balanced thereby increased or diminished These screws are so arranged that there is a preponderance of weight towards the south side of the magnet This is neutralized partly by the magnetic force tending to pull the north end down and partly by a slip of brass standing out horizontally towards the north side Let us suppose the system to be in equilibrium at a certain temperature, if the temperature rise (since brass expands more than steel), the leverage of the weight at the north side will increase more than that of the weight at the south There will thus be a slight preponderance towards the north, and this may be arranged so as to neutralize to a great extent the decrease in the magnetic moment which an increase of temperature produces

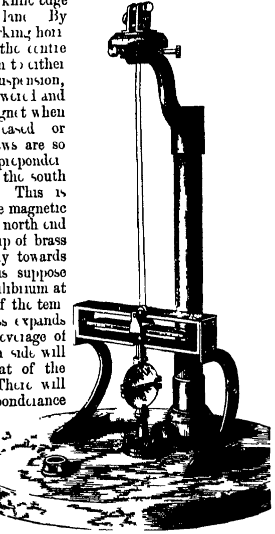


Fig 25 —Horizontal Force Magnetometer

21 *Magnetographs* —The arrangement by means of which these instruments are converted into self recording magnetographs is very simple In fig 23 we see a gas flame burning behind a vertical slit and placed end wise in order to render its light more intense The light from this illuminated slit passes through a lens, and being reflected from the mirror of the declination magnet throws an image of the slit upon some sensitized paper in the central box To speak more properly, two images are thrown, one reflected from the upper and movable half and the other from the fixed half of the mirror The sensitive paper is wrapped round a horizontal cylinder (fig 27), and the two images are therefore thrown upon different parts of this cylinder But before reaching the cylinder these two images are by means of a hemicylindrical lens (shown in fig 27) crushed up into two dots of light The cylinder moves round regularly by clock work once in twenty four hours, and hence the course on the moving paper of the dot of light which comes from the fixed half mirror will be a straight line, while that of the dot from the moving half mirror will be a curved line depending on the motions of the magnet When the paper is developed these lines appear black

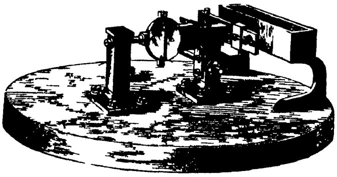


Fig 26 —Vertical Force Magnetometer

The arrangement for the horizontal force instrument is precisely similar to that for the declinometer, for the vertical force it is somewhat different, the illuminated slit being horizontal and not vertical, while the mirror oscillates on a horizontal axis and not on a vertical one, the hemicylindrical lens too and the cylinder are vertical and not horizontal It was found necessary to put the plane of motion of the vertical force magnet 15° out of the magnetic meridian for the following reason The axes of the telescopes are respectively 30° inclined to the tubes which go from the magnetometers to the central box, and hence had the vertical force magnet swung in the magnetic meridian it would have been necessary to place the mirror inclined at the angle of 15° to the axis of motion of the magnet This was tried, but it was found that in this position of the mirror the correction for temperature was so excessive that the instrument became a thermometer and not a magnetometer The mirror was therefore put in a plane passing through the axis of motion of the needle, the needle being made to move in a plane inclined 15° to the magnetic meridian

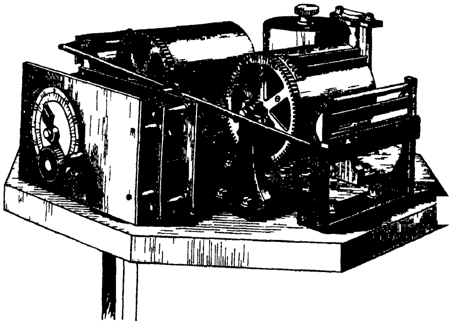


Fig 27 —Magnetograph.

22 *Scale Coefficients of Differential Instruments* —It is necessary to know the value of one division of the scale in the magnetometer or of one inch difference in the ordinate of the curve impressed on the photographic paper in the magnetograph In the declination instrument it is only necessary to obtain the angular deviation corresponding to one division, and this may be done at once by a series of measurements In the horizontal and vertical force instruments we wish to obtain the value of one division in parts of force There is more than one method by which this can be accomplished, but that of John Allan Broun is probably the simplest, and it is, we believe, the one adopted at most of the various observatories possessing self recording instruments It is given in the *British Association Reports*, 1859

23 *Temperature Coefficients of Differential Force Instruments* —Broun has devoted a great deal of attention to the subject of these coefficients, and has come to the conclusion that the best and most unobjectionable method of determining them is to

---

[1] All the magnets.

compare the instrumental readings on days when the temperature is high with the readings on days when the temperature is low

24 By differential instruments the components of a force affecting the magnet are determined in three directions at right angles to each other It does not, however, follow that this force is entirely due to changes in the magnetism of the earth We know that certain forces connected with the sun affect the earth s magnetism, and on certain occasions at least these forces manifest themselves as currents in the upper regions of the atmosphere and in the crust of the earth Now such currents will have a direct effect upon the needle as well as an indirect effect through the changes which they may produce in the magnetism of the earth The total influence on the needle will therefore be made up of these two elements, the one denoting the direct influence on the needle of the disturbing force, and the other the indirect influence through the change produced in the earth s magnetism No attempt has yet been made to separate the action of these two elements

25 Self recording instruments after the Kew pattern have been supplied to observatories at the following places —

Batavia
Coimbra (Portugal)
Lisbon
St Petersburg
Florence
Stonyhurst
Utrecht (declination only)
Melbourne
Mauritius
Kolaba (Bombay)
Vienna
Zi Ka Wei (China)
San Fernando (Spain)
Potsdam
Brussels
Nice

There are also self recording magnetographs of other patterns at Toronto, Montsouris (Paris), Greenwich, Wilhelmshaven (?), Cape Horn and Havana (?)

We understand that Professor W G Adams is at present engaged in making a comparison of simultaneous curves from various stations of these lists[1]

MAGNETIC POLES OF THE EARTH—SECULAR VARIATION

26 *Magnetic Poles of the Earth* —In the article MAGNETISM it has been shown that Dr Gilbert of Colchester had at a very early period grasped the important truth that the earth is a magnet a truth which was afterwards mathematically demonstrated by Gauss It was reserved for Halley the contemporary of Newton to show that the earth must be regarded as having two poles in the northern and two poles also in the southern hemisphere, so that, unlike ordinary magnets, its magnetic system has four poles altogether Before proceeding further it will be desirable to state what it was that Halley actually did and what are the conclusions to be derived from his investigations It has been remarked by Professor Stokes that while in an ordinary bar magnet we may practically regard the pole as having a physical reality and as being the cause of well known attractions and repulsions, we are not entitled *a priori* to assume that a point of maximum force in a large spherical magnet like the earth must necessarily be the seat of attractions and repulsions after the same manner as the pole of an ordinary bar magnet It is to be determined by observation to what extent the earth actually preserves an analogy to an ordinary magnet Now Halley s conclusions were derived from the pointing of the declination needle, since in his day there were no observations possible on total magnetic force He argued that there are two points or poles in the northern hemisphere to which the needle appears to be attracted, one in the upper region of America and one above Siberia So far this conclusion is hardly anything more than a formal one derived from the grouping together of observations He asserted that these would be as they are known to be if we imagine two such poles or foci of force each exercising a causal influence on the magnetic needle And the justification of Halley s way of regarding the earth is found in the fact that when force observations came to be made two such foci of force were actually found to exist We do not, however, mean to imply that these foci have causal properties exactly similar to the poles of a bar magnet, for this is not the case

In order to exhibit the process of reasoning which led Halley to his conclusion let us first imagine that the earth has only a single pole or force focus in the northern hemisphere, and that this is coincident with its geographical pole then, assuming that this pole has a causative influence on the needle s declination we should expect all needles to point everywhere due north If however this pole be not coincident with the north pole of the earth let us draw a meridian circle passing through the magnetic pole and complete it round the earth so as to divide the earth into two halves At all points in this meridian circle the needle might be expected to point due north, while in the one half of the earth so divided it should point to the east and in the other half to the west of true north In the next place let us imagine that the earth has two north magnetic poles or foci of equal strength, both being at the same latitude, while their difference in longitude is 180°, and let us draw a complete circle of meridian passing through these poles (fig 28) Let us start from a point in this circle under one of these poles and pursue our journey eastwards along a circle of latitude At first the needle will point due north As we move eastwards the needle will point westwards to the pole we are leaving until we come to a region half way between the two poles, where it will be equally solicited by each, and will therefore again point due north Let us call the space we have travelled over since we set out A As we proceed the needle will now be under the predominant influence of the second pole to our right, and will therefore point to the east until we arrive at the meridian under the second pole This second space which we have travelled over let us call B As we proceed we pass through a space C where the needle again points to the west until being once more equally influenced by the two poles it will point due north After this we pass through a space D of easterly variation until we arrive once more at the point from which we started

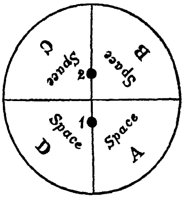


Fig 28

Thus there are now four spaces instead of two, and these are shown in fig 28 where the centre of the circle represents the north geographical pole of the earth and its circumference the equator If pole 2 be inferior in power to pole 1 the spaces B and C will be smaller in size than A and D

27 This last is an arrangement of things that agrees very well with the results of observation, if we add that the two poles are not precisely 180° removed from one another in longitude Fig 30[2] represents lines of equal magnetic variation in 1882 There are two lines extending throughout both hemispheres at all points of which there is no variation and also an oval shaped district in the northern hemisphere throughout all points in the circumference of which we have no variation These facts are inconsistent with the hypothesis of a single pole but they are quite consistent with that of two poles or foci of force one in northern America and the other in northern Asia the former being stronger than the latter In order to see this let us take our stand at the great line of no variation which passes through North America and travel eastwards We are just south of the American pole or focus, while the Asiatic pole or focus is nearly 180° off and hence the needle points due north As we proceed eastwards we leave the American or strongest pole to the westward of us, and hence we have a region of west variation which we have agreed to call A As we begin to approach the eastern side of Europe we get nearer the Asiatic pole or focus, and at length the line of no variation is reached, the tendency of the American pole to pull the needle to the west being balanced by the tendency of the Asiatic pole to pull it to the east After this, easterly variation predominates throughout a region B until at length we come to a point in the western boundary of the oval where we may imagine ourselves to be directly south of the Asiatic pole, while the American pole is nearly 180° distant, once more the needle points due north As we still travel eastwards we leave the Asiatic pole, which is now the predominant one, to our left, and hence we have here a region C of westerly declination At length we come to the eastern boundary of the oval, where the tendency of the Asiatic pole to pull the needle to the west is balanced by the tendency of the American or stronger pole (acting now towards the right) to pull it to the east, so that we have once more a point of no variation After this the American pole predominates, and we have a large region D of easterly variation until we travel round once more to the point from which we started

28 This train of argument receives, as we have already mentioned, corroboration from the fact that in the map of total force we perceive two foci of maximum force, one in northern America and the other in northern Asia that in America being the strongest This evidence was not however in existence at the time of Halley and his hypothesis of two poles does the greater credit to his sagacity, inasmuch as he had to deduce it from a comparatively small number of observations of declination and dip, those of force being altogether wanting

29 We have hitherto spoken of two poles or more properly, *foci of maximum force*, the positions of which are of course best pointed out in fig 29 , but we have seen that the existence of such

---

[1] We are indebted to Mr Gordon—and to his publishers Messrs Sampson Low & Co who have obtained them for us—for the sketches of the instruments for absolute determinations with the exception of that of Kater s compass for which we are indebted to Mr J J Hicks For the sketch of the self recording magnetographs together and in detail we are indebted to the Kew committee and to Mr G M Whipple, director of the Kew Observatory

[2] We are indebted for the admirable charts given in figs 29–32 to the kindness of the hydrographer Captain Sir Frederick Evans who in order to save time, allowed us to make use of the information he had embodied even before it was officially published, and who likewise placed his plates at our disposal

foci was first conjectured from the behaviour of the lines of variation or declination Now it will be noticed by looking at the variation map (fig 30) that all the lines of equal magnetic variation appear to converge to a point in the extreme north of the American continent This point is not however coincident with the chief focus of force which lies decidedly to its south but it is no doubt coincident with the point denoting a dip of 90°, the locality of which may be inferred from the map of magnetic dip (fig 31), and it is likewise no doubt coincident with the position of a zero of horizontal force which may be inferred from the map of horizontal force (fig 32) Thus we have a point to the extreme north of America which has the following properties —(1) the various lines of declination converge to it, (2) the needle points vertically down wards at it, and (3) the horizontal force vanishes at it At this point therefore the horizontally balanced needle having no horizontal force acting upon it will point in any direction

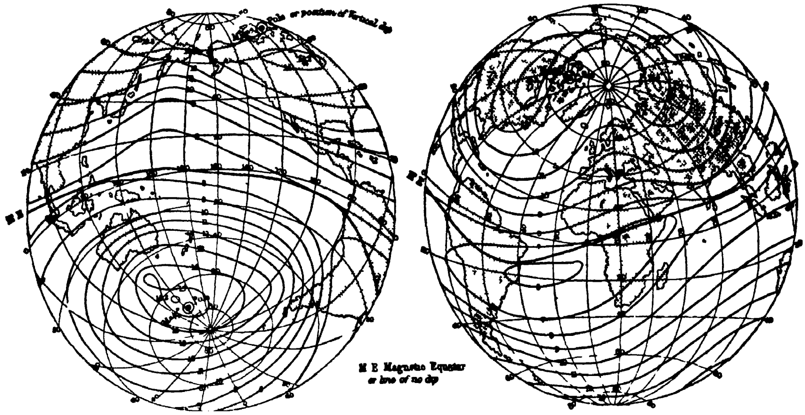

Pole or position of Vertical dip
M E Magnetic Equator or line of no dip

FIG 29 —The Earth s Magnetism as shown by the Distribution of Lines of Equal Total Force in Absolute Measure (British miles), with the Position of the Magnetic Poles and Equator —approximately for 1875

This point is strictly speaking the *pole of verticity* but inasmuch as there is only one such point in each hemisphere these may for convenience sake be termed the magnetic poles so that we speak .... centres or foci of maximum force and one pole in each hemisphere

In the northern hemisphere Sir Frederick Evans[1] assumes the stronger or American focus to be in 52° N and 90° W and the weaker or Siberian focus in 70 N and 115° E In the southern hemisphere he assumes the position of the stronger focus to be 65 S and 140° E and of the weaker focus probably 50 S and 130° E, these being thus not far separated from each other or from the magnetic pole The nearness together of the southern foci is probably the reason why the total force is greater at the southern than it is at the northern foci

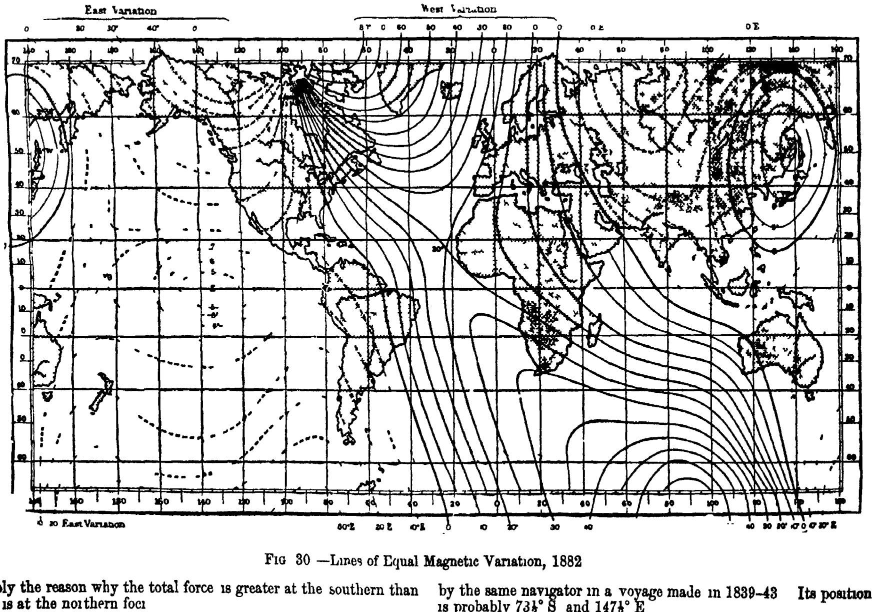


FIG 30 —Lines of Equal Magnetic Variation, 1882

The magnetic pole (of verticity) in the northern hemisphere was reached by Sir James Ross in 1831 The position of vertical dip was observed by him to be 70° 5 N and 96° 43 W The magnetic pole (of verticity) in the southern hemisphere was nearly attained by the same navigator in a voyage made in 1839–43 Its position is probably 73½° S and 147½° E

The line of no dip is called the *magnetic* or *dip equator*—its position is given in figs 29 and 31 The line connecting all the points where the magnetic intensity is least is called the *dynamic equator* It coincides very nearly with the dip equator

---

[1] *Elementary Manual for the Deviation of the Compass in Iron Ships.*

30 *Secular Variation* —The earth then as a magnet must be supposed to have two sets of centres of force We shall next attempt to show that these centres cannot be regarded as constant both in position and intensity

It should be premised that, while there is no well established evidence to show that either the pole of verticity or the centre of force to the north of America has perceptibly changed its place, there is on the other hand very strong evidence to show that we have a change of place on the part of the Siberian focus and also on the part of its analogue in the southern hemisphere

Table I (p 166) given by Gilpin (*Phil Trans* 1806)[1] exhibits the change in the position of the needle in Great Britain from the earliest observations up to the beginning of the present century

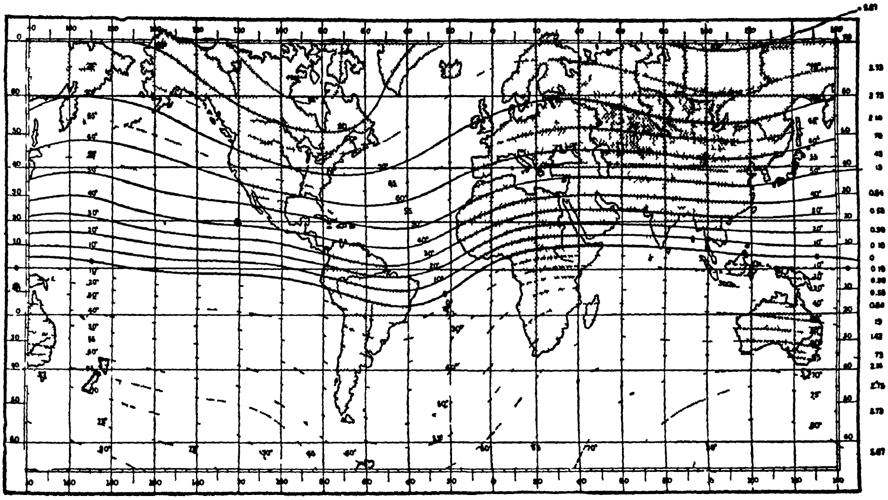


FIG 31 —Lines of Equal Magnetic Dip 1882

31 Between the dates recorded in this table the needle has been pointing more and more to the west which implies either a relative increase in the power of the American as compared to the Siberian focus or a motion of the Siberian focus from west to east On the first supposition the lines to the eastward of the Siberian focus—for instance the line of no variation depending on a balance between it and the American focus—should be drawn in towards it or they should travel westwards but if the latter supposition is true or this focus has been moving eastwards while retaining its force the lines to the east of it should be found moving eastwards also There is strong evidence that the latter is the case and that in the northern hemisphere there has been a long continued progression to the eastwards of the system of magnetic lines on both sides of the Siberian focus In the southern hemisphere also we have proof that the analogous focus has been travelling not from west to east but from east to west

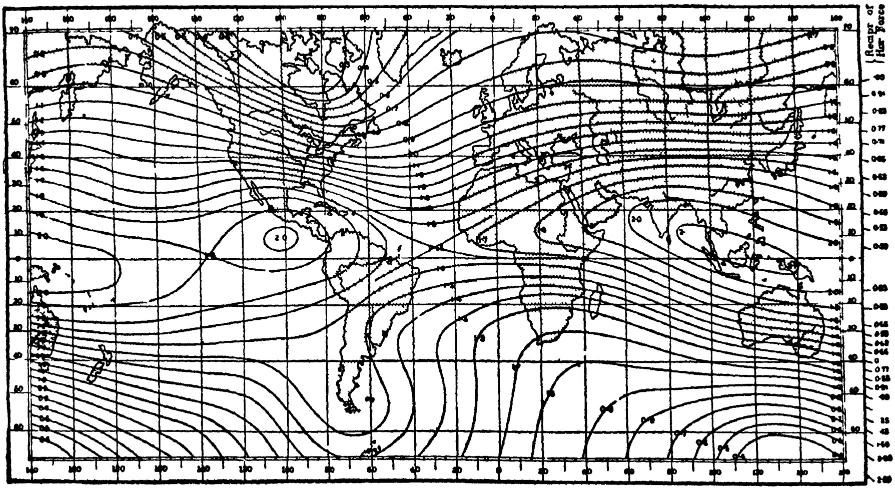


FIG 32 —Lines of Equal Horizontal Force 1882

32 There is some reason to believe that the eastward motion of the Siberian focus has been recently reversed and that it is now going from east to west Table II shows the declination observed at Bushey Heath (Herts) during 1817 20 and at Kew from 1858 to 1882

It would appear from Table II that the maximum westerly declination was reached in 1818 and that the needle has since that date been travelling eastwards A similar change has taken place at other stations, and, although these changes are not strictly simultaneous at the various stations they have yet been sufficiently general and near together in point of time to indicate that some change has probably taken place in the movement of one set of the magnetic foci of force

---

[1] Taken from Walker's *Magnetism*

33 Halley sought to explain the four pole theory and to account

TABLE I —*Secular Change of Variation in Great Britain*

Observer	Date	Declination	Mean Annual Westward Change
		°	
Burroughs	1580	11 15 E	
Gunter	1622	6 0 E	7 5
Gellibrand	1634	4 6 E	9 5
Bond	1657	0 0 E	10 6
Gellibrand	1665	1 22 W	10 2
Halley	1672	2 30 W	9 7
Halley	1692	6 0 W	10 5
Graham	1723	14 17 W	16 0
Graham	1748	17 40 W	8 1
Heberden	1773	21 9 W	8 4
Gilpin	1787	23 19 W	9 3
Gilpin	1795	23 57 W	4 7
Gilpin	1802	24 6 W	1 2
Gilpin	1805	24 8 W	0 7

TABLE II —*Changes of Declination in England —at Bushey Heath for* 1817–20, *and at Kew from* 1858

	Declination West		Declination West
	° ′ ″		° ′ ″
1817	24 36 4	1869	20 26 24
1818	24 38 25	1870	20 18 52
1819	24 36 14	1871	20 10 31
1820	24 34 30	1872	20 0 31
1858	21 54 8	1873	19 57 44
1859	21 47 22	1874	19 51 58
1860	21 39 51	1875	19 41 14
1861	21 31 36	1876	19 31 53
1862	21 23 32	1877	19 22 22
1863	21 13 16	1878	19 13 50
1864	21 3 35	1879	19 6 10
1865	20 59 3	1880	18 57 59
1866	20 51 10	1881	18 50 30
1867	20 40 26	1882	18 44 47
1868	20 33 9		

TABLE III —*Exhibiting certain Years Values of Declination at Various Places*

Toronto		Makerstoun		Trevandrum		Cape of Good Hope		Hobart Town	
	Declination		Declination		Declination		Declination		Declination
	°		°		°		°		°
1841	1 14 3 W	1841	25 33 7 W	1854	0 25 896 E	1605	0 30 0 E	1843	9 53 32 E
1842	1 19 1 W	1842	25 28 4 W	1855	0 26 026 E	1609	0 12 0 W	1844	9 54 93 E
1845	1 29 1 W	1843	25 22 9 W	1856	0 26 400 E	1622	2 0 0 W	1845	9 56 47 E
1846	1 30 8 W	1844	25 17 1 W	1857	0 27 278 E	1675	8 14 0 W	1846	9 58 42 E
1847	1 33 2 W	1845	25 11 3 W	1858	0 28 769 E	1691	11 0 0 W	1847	9 59 28 E
1848	1 35 4 W	1846	25 6 0 W	1859	0 30 406 E	1751	19 15 0 W	1848	9 60 61 E
1849	1 36 9 W	1847	24 59 6 W	1860	0 32 034 E	1775	21 14 0 W		
1850	1 38 6 W	1848	24 51 8 W	1861	0 34 318 E	1788	24 4 0 W		
1851	1 40 9 W	1849	24 45 2 W	1862	0 36 654 E	1792	24 31 0 W		
1856	1 56 3 W	1850	24 39 0 W	1863	0 39 123 E	1818	26 31 0 W		
1857	2 0 5 W	1851	24 31 3 W	1864	0 41 603 E	1836	28 30 0 W		
1858	2 4 5 W	1852	24 25 2 W	1865	0 44 007 E	1839	29 9 0 W		
1859	2 7 4 W	1853	24 18 7 W	1866	0 46 310 E	1841	29 6 2 W		
1860	2 10 6 W	1854	24 11 8 W	1867	0 47 590 E	1842	29 5 9 W		
1861	2 14 4 W	1855	24 5 3 W	1868	0 48 687 E	1843	29 6 0 W		
1862	2 15 7 W			1869	0 49 735 E	1844	29 6 2 W		
1863	2 19 1 W					1845	29 7 4 W		
1864	2 21 9 W					1846	29 8 7 W		
1865	2 24 8 W					1847	29 12 4 W		
1866	2 27 6 W					1848	29 14 0 W		
1867	2 29 8 W					1849	29 16 2 W		
1868	2 33 2 W					1850	29 18 8 W		
1869	2 37 1 W								
1870	2 41 9 W								
1871	2 47 9 W								

TABLE IV —*Exhibiting certain Years' Values of Dip and Horizontal Force at Various Places The years in this Table are from April to April thus* 1845 *means the year from* 1st *April* 1845 *to* 31st *March* 1846

London or Kew				Toronto				Hobart Town				Cape of Good Hope	
	Dip		Hor Force		Dip		Hor Force		Dip		Hor Force		Dip
	°								°				
1857	68 24 87	1857	3 7899	1845	75 15 50	1845	3 5476	1842	70 42 2	1846	4 5054	1841	53 9 1
1858	68 22 56	1858	3 7950	1846	75 14 58	1846	3 5419	1843	70 38 2	1847	4 5001	1842	53 15 3
1859	68 21 41	1859	3 8007	1847	75 15 50	1847	3 5384	1844	70 33 3	1848	4 4991	1843	53 20 2
1860	68 19 29	1860	3 8063	1848	75 18 32	1848	3 5339	1845	70 32 0	1849	4 4997	1844	53 29 4
1861	68 17 42	1861	3 8121	1849	75 18 94	1849	3 5367	1846	70 33 0	1850	4 4998	1845	53 29 3
1862	68 14 89	1862	3 8165	1850	75 19 98	1850	3 5322	1847	70 34 5				
1863	68 11 71	1863	3 8216	1851	75 20 42	1851	3 5299	1848	70 35 7				
1864	68 9 31	1864	3 8284	1852	75 20 52	1852	3 5154						
1865	68 8 50	1865	3 8306										
1866	68 5 44	1866	3 8391										
1867	68 2 62	1867	3 8467										
1868	68 2 13	1868	3 8493										
1869	68 0 41	1869	3 8551										
1870	67 57 98	1870	3 8585										
1871	67 56 12	1871	3 8640										
1872	67 53 60	1872	3 8712										
1873	67 51 19	1873	3 8777										
1874	67 49 64	1874	3 8828										

for the secular change by imagining a solid globe or *terella*,[1] concentric with the earth but rotating independently of the external shell and having a slightly different period of rotation,—the shell having two poles and the terella two others While continuing to admire Halley s sagacity, we shall not now be disposed to allow such a constitution of the interior of the earth, but will rather be led to look to some external influence as the cause of the secular variation

While we have strong evidence that the Siberian focus has changed its position, we cannot assert that the American focus has been absolutely stationary, or that neither focus has experienced any changes of force On these points we must be content to be guided by observation alone

34 It has been supposed by some magneticians that it is possible to compute with something like certainty the particulars of the motions of the magnetic foci Hansteen more especially (1811–19) computed both the geographical positions and probable periods of revolution of this dual system of foci of force round the terrestrial pole Sir Frederick Evans has discussed in connexion with the subject all the most recent observations,[2] and points out two objections to any such theory as that of Hansteen, viz , (1) that, while a magnetic turning point has been reached in certain regions, there are large portions of the earth in which this change has not yet been accomplished, and (2) that in certain districts of the earth very great changes in force have taken place "If we turn, he says, "to the continent of South America and its adjacent seas, we shall find a diminution of the intensity of the earth s force now going on in a remarkable degree An examination of the recent observations made by the 'Challenger officers at Valparaiso and Monte Video, compared with those made by preceding observers, shows that within half a century the whole force has respectively diminished one sixth and one seventh,—at the Falkland Islands one ninth On the whole, while there is strong evidence that the Siberian focus has until recently been travelling eastwards, and its analogue westwards, and evidence less conclusive that recently a turning point in this motion has been reached, we are disposed to think with Sir Frederick Evans that a formal theory like that of Hansteen does not agree with recent observations We shall revert to this subject

35 In Tables III and IV certain yearly values of declination, dip, and horizontal force are given for various stations

Inequalities in or connected with Terrestrial Magnetism depending on the Sun

36 As there is a marked likeness between the ways in which the sun dominates over the two great divisions of terrestrial phenomena, meteorology and magnetism, let us endeavour to describe the sun s effect upon the latter by referring to its influence on the former, the chief peculiarities of which are well known to all We find that the temperature of the air at a given station is subject to a diurnal fluctuation having its minimum value shortly before sunrise and its maximum early in the afternoon We find likewise that the mean temperature for the day as well as the amplitude of this diurnal oscillation depends upon the season of the year, both being greatest about midsummer and least about midwinter Now, if this were the only manifestation of solar influence upon this particular element, it would be possible to predict the temperature for any hour of any day once the mean temperature, the diurnal variation of temperature, and the modification of these for different seasons of the year had been well ascertained But this amount of regularity is very far from taking place,—the march of temperature being frequently interrupted, cloaked, perhaps even reversed, by the advent of peculiar weather Thus we may have very cold weather in midsummer and very warm weather in midwinter, or we may have a very cold afternoon and a very warm early morning, by which means the ordinary conditions of temperature will be completely reversed In like manner weather interferes even to a greater extent with the diurnal oscillation of the atmospheric pressure so that, in British latitudes at least, it is only possible to obtain this correctly by means of a long series of observations

Weather, however, does not consist of a perfectly lawless interference with periodical phenomena, but is subject to laws of its own, some of which we are beginning to discover Sometimes weather may exalt or depress the diurnal fluctuation of temperature without otherwise affecting its character, but sometimes too the turning points and the general appearance of this fluctuation are greatly influenced by peculiar weather

37 Now it is believed that we have something of this kind in those fluctuations depending on the sun to which the elements of terrestrial magnetism are subject Let us take the declination as the most easily studied of the three magnetic elements, and suppose that we are engaged in considering the traces denoting the fluctuations of declination as derived from a set of self recording magnetographs in Great Britain Here we shall at once be able to recognize in an unmistakable manner the diurnal variation depending upon the position of the sun, in virtue of which a freely-suspended magnetic needle reaches the easterly extreme of its range about eight in the morning, and the westerly about two in the afternoon We shall likewise perceive that the range of this diurnal fluctuation is greatest at midsummer and least at midwinter In fine, the characteristics of this fluctuation depending as they do upon the hour of the day and the season of the year are not very different from those exhibited in the diurnal fluctuation of atmospheric temperature But, however thoroughly we may have ascertained the mean declination and its diurnal oscillation, as well as the modifications of these depending on the season of the year, we shall nevertheless find it impossible to predict the exact position of a freely suspended magnet at any moment of a particular day Here then too we have something which may be called magnetic weather, and which interferes with the regular progress of the systematic fluctuations of the magnet Magnetic weather has, like its meteorological analogue, a set of laws of its own, some of which we are beginning to find out Sometimes magnetic weather may exalt or depress the diurnal fluctuation of declination without affecting its character, but it is imagined that at other times the turning points and general appearance of this fluctuation may be greatly influenced by peculiar magnetic weather

38 There is, however, a kind of magnetic change which, so far as we know at present is not analogous to anything in meteorology and introduces an additional element of complexity in any attempt to analyse the fluctuations of terrestrial magnetism We mean the well known magnetic disturbances or storms which occur simultaneously in places very widely apart Under these circumstances it becomes a question how we can best deal in a practical manner with this complicated system of things

We do not think that with our present knowledge any better system can be adopted than that first introduced by Sir Edward Sabine in his discussion of the results of the colonial magnetic observatories Suppose that we have hourly magnetic observations at a station, then first of all we should arrange these into monthly groups—each hour by itself We should then reject as disturbed observations all those which differ by more than a certain amount from their respective normals of the same month and hour,—the normals being the hourly means in each month after the exclusion of all the disturbed observations This method enables us by its exclusion of disturbances to ascertain with much accuracy the true form of the solar diurnal variation of the magnetic elements at a given place corresponding to every month of every year, provided only that the observations are sufficiently numerous On the other hand it will probably fail in accurately giving us the variations from day to day of the ranges of these diurnal fluctuations caused by the advent of peculiar magnetic weather,—inasmuch as the records of the extreme effects of such weather will probably be cut off from the undisturbed observations and reckoned among the disturbances

For instance it is known that the solar influence on terrestrial magnetism varies from year to year, and it is suspected that there are also short period fluctuations of solar influence It would not, however, be a safe proceeding to attempt to estimate numerically this last mentioned element of fluctuation by taking the successive diurnal ranges of those observations at any station, reckoned as undisturbed by the above process, and plotting them as successive ordinates of a curve, and then supposing that this curve would give us a true graphical representation of solar changes It would rather probably represent such changes with the tops and bottoms of the larger fluctuations cut off But if the undisturbed observations fail in this respect we can hardly be wrong in supposing that there has been eliminated from them, as far as possible all influence due to magnetic storms, and hence that they will afford us a much better means of estimating small fluctuations, such, for instance as those due to the moon, than we could have had without their aid

Finally, with regard to that portion of the observations selected as disturbed, we are probably not certain that every such observation represents a true disturbance, or that the absolute times of occurrence of the various observations selected as disturbed at one station will be the same as those at another Nevertheless Sir Edward Sabine has shown that at the Kew Observatory certain laws of disturbance deduced from the whole body of observations selected as disturbed are closely reproduced when this selection is made on a narrower basis—ninety five days of prominent disturbance being alone taken With these prefatory remarks we shall now proceed to discuss the diurnal inequality of terrestrial magnetism

39 *Total Diurnal Inequality Defined* —It will be seen further on that disturbed as well as undisturbed observations are subject to a diurnal variation, but these two variations are different and the name *diurnal inequality* is generally given to the compound variation which is the joint resultant of the two *Solar diurnal variation* is that portion of the compound inequality which refers to undisturbed observations, while that which refers to disturbances has received the name of *disturbance diurnal variation* It would appear that in the United Kingdom, and perhaps throughout Europe, the total diurnal inequality is not very greatly different either in character or range from its most important component the solar diurnal variation, at least so far as the

---

[2] In his lecture to the Royal Geographical Society March 11, 1878

declination is concerned When the diurnal oscillation of a freely-suspended magnet was first observed, the subject of magnetic disturbances was not understood and the early individual determinations which have been handed down to us are not such as to justify the expenditure of any very great labour upon them for the purpose of separating the disturbed from the undisturbed observations Inasmuch, however, as the total diurnal inequality of declination (which is in reality the element given by these early observations) does not greatly differ from the solar diurnal variation, we may with much justice and little risk of error give the history of these early observations in connexion with that of the solar diurnal variation of declination which is by far the best known and perhaps the most important, of all the various magnetic changes produced by solar influence

40 *Solar Diurnal Variation of Declination* —Graham, an instrument maker of London, discovered in 1722 that a freely-suspended magnetic needle is subject to a diurnal oscillation of definite character [1] The next observer was Canton who in 1756 began a series of nearly four thousand observations which he communicated to the Royal Society on December 13 1759, and from which he concludes that the range of the diurnal variation is greater in summer than in winter Macdonald's observations at Fort Marlborough in Sumatra in 1795 (*Phil Trans*, 1796) and Duperrey's in the tropics in 1825, were perhaps the first that might lead us to conclude that the amplitude of the diurnal oscillations of the needle is less in the tropics than in middle latitudes and that the motion of the needle in the southern hemisphere is in the opposite direction to that in which it moves in the northern hemisphere at the same hour

41 *Semiannual Inequality* —The existence of these early observations had led some magneticians prematurely to conjecture that there must be a line somewhere near the equator at which there is no hourly variation in declination In 1817 Sabine communicated to the Royal Society the results of five years observations at St Helena, showing that at that station for the half of the year beginning at the vernal and ending at the autumnal equinox the motion of the needle corresponds nearly to that in the northern hemisphere, whilst for the other half it corresponds nearly to that in the southern hemisphere Sabine afterwards confirmed and extended his conclusions regarding the semiannual inequality by discussing the results obtained at the various colonial magnetic observatories More recently as the result of twelve years observations at Trevandrum, at an observatory established by the rajah of Travancore John Allan Broun gave in a very complete form the laws of change of the solar diurnal variation of magnetic declination near the equator showing the extinction of the mean movement near the equinox

42 Perhaps the best way of exhibiting what really takes place is the following, which is that adopted by Sabine

The mean annual value of the solar diurnal variation is of what may be called the northerly type in places of middle latitude in the northern hemisphere and of what may be called the southerly type in places of middle latitude in the southern hemisphere Now let us take a northern station, and consider the mean form of its solar diurnal variation for the six months beginning with the vernal equinox Here we shall have an oscillation of the northerly type with a range greater than the annual range For these six months therefore we may imagine that the annual range has been supplemented by the superposition on it of a variation with a type similar to its own At the same station during the other six months the solar diurnal variation is less than the mean of the year, as if the annual variation had been depressed by the superposition on it of a variation with a type the opposite of its own that is to say, with a southerly type At a station in the southern hemisphere again, the mean annual form of the solar diurnal oscillation is of the southerly type, reduced during the six months beginning with the vernal equinox by the superposition on it of a variation of northerly type, and increased during the other six months as if by the superposition of a variation of southerly type Thus when the sun is north of the equator we may superpose a variation of the northerly type upon both hemispheres, with the effect of increasing the range in the northern hemisphere and diminishing it in the southern, and while the sun is south of the equator we may superpose a variation of the southern type upon both hemispheres with the effect of diminishing the range in the northern and increasing it in the southern hemisphere

Near the equator as at Trevandrum where Broun made his observations, we find the mean annual value of the solar diurnal variation to be extremely small if not altogether evanescent During the six months beginning with the vernal equinox the type is entirely northerly, while for the remaining six months of the year it is entirely southerly in character In fine, at this station the solar diurnal variation changes its character at the equinoxes, which time we have, as already observed, an extinction of the mean movement,—not indeed an absence of a variation, but rather a variation having an undecided character, which for a few days may be of one type and then of the very opposite There is movement, but no mean movement

43 In the following table (V) the solar diurnal variation is given for Kew, Trevandrum, and Hobart Town Of these places the first denotes a station in middle latitude (northern hemisphere), the second an equatorial station, and the third a station in middle latitude (southern hemisphere)

Astronomical Hours	Kew			Trevandrum			Hobart Town		
	April to Sept	Oct to March	Whole Year	April to Sept	Oct to March	Whole Year	April to Sept	Oct to March	Whole Year
0	−6 15	−4 12	−5 13	−1 30	+0 07	−0 61	+0 55	+2 35	+1 35
1	−7 42	−4 96	−6 19	−1 25	+0 85	−0 45	+2 15	+4 85	+3 50
2	−6 94	−4 67	−5 81	−0 8	+0 56	−0 15	+3 15	+5 95	+4 55
3	−5 21	−3 35	−4 28	−0 35	+0 61	+0 13	+3 30	+5 50	+4 40
4	−3 25	−1 95	−2 60	+0 03	+0 53	+0 28	+2 40	+4 30	+3 35
5	−1 47	−1 05	−1 26	+0 15	+0 33	+0 24	+1 30	+2 70	+2 00
6	−0 32	−0 46	−0 39	+0 0	+0 22	+0 18	+0 75	+1 55	+1 15
7	+0 22	+0 21	+0 22	−0 15	+0 23	+0 04	+0 20	+0 80	+0 50
8	+0 44	+0 92	+0 68	−0 19	+0 19	−0 0	−0 30	+0 30	+0 00
9	+0 52	+1 45	+0 99	−0 8	+0 13	−0 08	−0 85	−0 25	−0 55
10	+0 70	+1 77	+1 24	−0 20	+0 09	−0 06	−1 10	−0 70	−0 90
11	+0 90	+1 84	+1 37	−0 07	+0 10	+0 01	−1 15	−0 85	−1 00
12	+1 19	+1 67	+1 43	+0 07	+0 11	+0 09	−1 10	−0 80	−0 95
13	+1 23	+1 34	+1 29	+0 18	+0 08	+0 13	−0 75	−0 75	−0 75
14	+1 56	+1 22	+1 39	+0 27	+0 02	+0 15	−0 40	−0 70	−0 55
15	+1 93	+1 09	+1 51	+0 29	−0 11	+0 09	−0 15	−0 65	−0 40
16	+2 58	+1 17	+1 88	+0 31	−0 28	+0 02	−0 02	−0 78	−0 40
17	+3 60	+1 43	+2 51	+0 18	−0 45	+0 01	−0 10	−1 40	−0 75
18	+4 59	+1 54	+3 07	+1 02	−0 66	+0 18	−0 23	−2 37	−1 30
19	+5 31	+1 8	+3 58	+1 48	−0 81	+0 32	−0 50	−3 80	−2 15
20	+5 20	+2 40	+3 80	+1 20	−0 72	+0 24	−1 2	−5 25	−3 25
21	+3 57	+2 39	+2 98	+0 47	−0 36	+0 06	−2 10	−5 30	−3 70
22	+0 38	+0 54	+0 46	−0 32	−0 13	−0 22	−2 20	−3 80	−3 00
23	−3 18	−2 18	−2 68	−0 93	−0 07	−0 50	−1 40	−0 80	−1 15

In this table deflexions towards magnetic east are reckoned positive deflexions towards magnetic west negative The scale is in minutes of arc

Also in fig 33 we have a graphical representation of the solar diurnal variation for the whole year at these three stations, from which it will be seen that the range at Trevandrum is extremely small, and that the curve for Hobart Town is opposite in appearance to that at Kew

Fig 33

Finally, in fig 34 we have a graphical representation of the semiannual inequality or difference from the whole year's mean of the two half yearly means of Table V, the one half year (that with thick lines) commencing at the vernal and the other at the autumnal equinox It will be seen from this figure that the semiannual inequality is of the same character in both hemispheres, the likeness extending even to its minor peculiarities

44 *Change from Month to Month* —Charles Chambers, director of the Kolaba Observatory, Bombay, remarks (*Trans Roy Soc*, December 10, 1868) that "the regular progression from month to month in the diurnal variation is so distinctly shown in the Bombay observations as to lead, on a first inspection, to the supposition that the law of variation is identical throughout the year, the extent only (including a reversal of direction) varying from month to month But in this respect a different exposition of the character of the variation in different months shows that the 1st thought would be inaccurate He then proceeds to discuss

---

[1] See Walker *Terrestrial and Cosmical Magnetism*

[2] This is the name used by Sabine but its appropriater questioned

at length the monthly values of the solar diurnal variation at Bombay Broun has likewise (Trevandrum observations) discussed at length the solar diurnal variation at the Trevandrum Observatory It would hardly be of service to reproduce here the results of these discussions, but when such analyses become sufficiently extensive they may be expected to throw light upon the cause of the solar diurnal variation

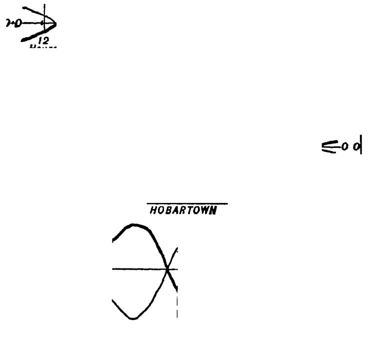


Fig 34

In the following table we have mean monthly values of the declination range at the Kew Observatory corresponding to forty eight points in the year—derived from sixteen years observations —

TABLE VI —*Containing Monthly Means (unit=22 04) for Forty eight Points in the Year of the Kew Solar Diurnal Declination Ranges Thus January* (0) *gives the monthly mean of which the middle date is the very commencement of the year, January* (1) *that for one week after the commencement, and so on*

	Mean Value		Mean Value		Mean Value
Jan (0)	312	May (0)	599	Sept (0)	594
(1)	323	(1)	581	(1)	577
(2)	340	(2)	573	(2)	554
(3)	362	(3)	586	(3)	532
Feb (0)	385	June (0)	596	Oct (0)	513
(1)	401	(1)	605	(1)	496
(2)	418	(2)	610	(2)	478
(3)	438	(3)	604	(3)	463
March (0)	467	July (0)	601	Nov (0)	445
(1)	508	(1)	597	(1)	418
(2)	548	(2)	591	(2)	389
(3)	587	(3)	593	(3)	360
April (0)	61	Aug (0)	594	Dec (0)	340
(1)	632	(1)	601	(1)	322
(2)	683	(2)	611	(2)	308
(3)	620	(3)	606	(3)	308

It will be seen from this table that while we have a maximum about the summer and a minimum about the winter solstice we have unmistakable indications of maxima at or about the equinoxes This does not take place at a tropical station such as Trevandrum

45 *Behaviour near the Magnetic Pole* —Figs 33 and 34 exhibit the most prominent features of the solar diurnal variation of declination in the extra tropical regions of the northern hemisphere If an observer stand over the centre of the needle and look towards the marked end, or that which points to the north he will perceive a deflexion towards his right hand which will reach its extreme about 8 A M and a deflexion towards his left hand which will reach its extreme about 2 P M But are these deflexions to the right and left hand of geographical or of magnetical north? This question has been answered by Sabine in his discussion of the results of hourly observations of the magnetic declination at Port Kennedy (*Phil Trans*, 1863, p 660) This station is 72° 0 49 N lat and 94° 19 W long, and here the marked end of the needle while it points towards the magnetic pole points in reality about 35° to the west of south Now the marked end of the needle when viewed at 8 A M is seen at Port Kennedy to have moved to the geographical west but to the magnetical east It would thus seem that throughout the extra tropical regions of the northern hemisphere the 8 A M deflexion of the needle is always towards the magnetic east but not always towards the geographical east, while the deflexion at 2 P M will always tend towards the magnetical west but not always towards the geographical west In fine the oscillations have reference to the north magnetic pole of the earth and not to the north geographical pole No observations of this nature have been made in the southern hemisphere

46 *Long Period Inequalities of Declination Range* —It was first observed by Lamont that the yearly values of the diurnal range of magnetic declination at Munich presented signs of a long period variation In 1852 Sabine (*Phil Trans*, 1852, p 103) showed that this inequality corresponded in its progress with that of the frequency of black spots on the surface of the sun

The existence of black spots on the disk of the sun was long ago known to the Chinese In Europe they were first scientifically observed after the invention of the telescope and it was deduced from their behaviour that the sun revolves about his axis in about twenty six days Hofrath S hwabe of Dessau from a long series of forty years observations of the sun was the first to show that the state of the sun s surface as regards spots was not uniform, but that their frequency was subject to an inequality the average period of which was about eleven years Other inequalities both of longer and shorter periods have been supposed to exist but the eleven yearly period is the most prominent and is best assured Although the sun spot catalogue of Schwabe is the first with pretensions to completeness yet Professor Rudolf Wolf has endeavoured to render observations of sun spots made at different times and by different observers comparable with each other, and has formed a list exhibiting approximately the relative number of sun spots for each year This list extends back into the 17th century, and is of great value in confirming past all doubt the existence of the eleven yearly period It will appear below that the sun is probably to be regarded as giving out most light and heat at those times when sun spots are most frequent The most accurate and now universally adopted method of estimating sun spots is to take the spotted area expressed in millionths of the sun s visible hemisphere

To return from this digression —the correspondence between sun spots and declination ranges detected by Sabine was of such a nature that years of large declination range agreed with those of many sun spots and *vice versa* In the same year with Sabine (1852) Dr Rudolf Wolf and M Gautier independently remarked the same coincidence Subsequent discussions have entirely confirmed the fact of this connexion and in May 1879 William Ellis (*Phil Trans*, 1880 p 541) showed that the observations made at the Greenwich Observatory during the years 1841–77 indicated a relation of this nature between the diurnal ranges of horizontal force as well as those of magnetic declination on the one hand and the amount of sun spot frequency on the other The general character of this coincidence between sun spot frequency and declination range is exhibited graphically in fig 39 below

47 *Ratios of Ranges in Years of Maximum and Years of Minimum Sun Spot Frequency* —Broun (*Trans Roy Soc of Edin*, vol xxvii) has shown that the ratios of the diurnal ranges of declination in years of maximum to those in years of minimum sun spot frequency for places widely apart on the surface of the earth are very nearly alike This will be seen from the following table —

TABLE VII —*Ratios of Declination Ranges in Years of Maximum and of Minimum Sun Spot Frequency*

Place	Mean Ratio $\left(\frac{\max}{\min}\right)$	Observer
Paris	1 71	Cassini and Arago
Gottingen	1 74	Gauss
Munich	1 66	Lamont
Dublin	1 52	Lloyd
Hobart Town	1 57	Kay
Toronto	1 51	Younghusband and Lefroy
Trevandrum	1 56	Broun

48 *Closeness of Correspondence—Lagging behind of Ranges* —Stewart has shown from a discussion of the declination ranges at Kew Trevandrum, and Prague (*Proc Roy Soc* March 22 1877, February 8 1878, May 16 1878) that this correspondence between the state of the sun s surface and the diurnal range of declination extends to inequalities of short period as well as to that of which the period is approximately eleven years but that a particular state of the sun s surface precedes in point of time that of the declination range to which it corresponds —in fine, that the solar cause precedes the terrestrial effect which latter lags behind to an extent that is sometimes considerable These conclusions have been confirmed by Ellis (*ut supra*) and have likewise been extended by him to the horizontal force The close nature of this correspondence as well as the lagging behind of the terrestrial magnetic effect will be seen from fig 35

There are indications that this lagging behind of the magnetic effect is greater for sun spot inequalities of long than for those of short period, a method of behaviour quite similar to what we find in meteorological phenomena

49 *Analysis of Long Period Inequalities* —We possess no sun spot

data sufficiently accurate for a discussion, in a complete manner, of questions relating to solar periodicity before the time when Schwabe had finally matured his system of solar observations, which was not until the year 1832. We have, however, a much longer series of the diurnal ranges of magnetic declination, which we have seen to follow very closely all the variations of sun-spot frequency, so it is conceivable that they may give us a better estimate of true solar activity than that which can be derived from the direct measurement of spotted areas.

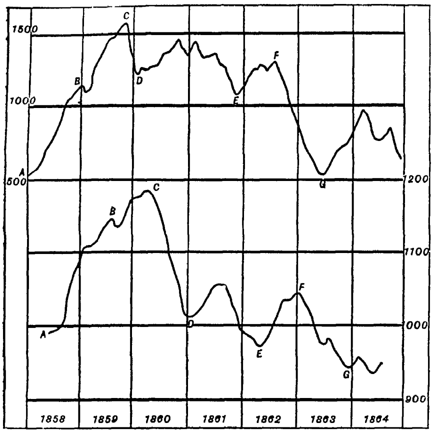


Fig. 35.

These considerations have induced Messrs Stewart and Dodgson to attempt an analysis of the diurnal ranges of magnetic declination, their method being that which has been pursued by Baxendell and probably other astronomers with observations of variable stars.[1] The observations at their disposal for this research were those which had been used by Professor Elias Loomis in his comparison of the mean daily range of the magnetic declination with the extent of the black spots on the sun (*American Journal of Science and Arts*, vol. l. No. cxlix.). These observations are recorded as monthly means of diurnal declination range, and it was found necessary to multiply each by a certain factor, first on account of the change of declination range from one month to another, and secondly to bring them all to the standard of the Prague observations,—Prague being the place where the longest series of such observations has been made. For this latter purpose precisely the same corrections were applied as those made by Professor Loomis.

The result of this analysis has been to indicate the existence of three inequalities,—two dominant ones with periods of about ten and a half and twelve years and a subsidiary one with a period of about sixteen and a quarter years. By these means the observed annual values of declination range have been reproduced with an average error of 3·9. The amount of agreement between the observed and calculated values will be seen from the following diagram (fig. 36).

50. Notwithstanding the considerable amount of agreement between the results of observation and calculation which appears in the diagram, it would seem that the series of observed values at present obtainable is too short to render the analysis a very accurate one. It will certainly not bear carrying back forty or fifty years beyond its starting point, which was in 1784, and it would be very hazardous to carry it forward any considerable length into the future. It will be seen that calculation indicates a maximum of declination range about 1884, but not so pronounced a maximum as that of 1871. Here then we have a prevision which observation will either fulfil or contradict, giving us a practical test of the value of this analysis.

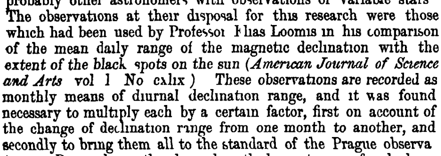


Fig. 36.

51. The remarks now made would seem at first sight to imply that we are not yet furnished with sufficient yearly records either of declination ranges or of accurate sun-spot observations to enable us to analyse the long period solar inequality with such completeness as to carry our calculations more than a very short distance into the future with any chance of success, and that we may have to wait for another hundred years' observations before we are able to do so. On reflection, however, it would seem that long-period inequalities may be caused by the superposition of those of short period, and thus that an analysis of the latter may lead to that of the former. It would relieve us if this were found to be the case, for the observations at our disposal may be sufficient to enable us completely to analyse short-period inequalities, assuming that we have in such the elements of a true periodicity.

A remark made by the authors of the above analysis would seem to indicate that a connexion of this nature between long and short periods does in all probability exist. It is a well-known fact that the so-called eleven-yearly oscillations of declination range are at certain times large and at other times small. Thus, for instance, they have been large for the last forty years, but they were small about the earlier part of the present century. Now it is clear from an inspection of the observations (see fig. 36) that a series of large oscillations is accompanied with an exaltation of the base line, or line denoting average efficiency, while a series of small oscillations is accompanied with a depression of the same. The result is a long-period curve of the base line, the beat period, so to speak, of the eleven-yearly inequality.

Now a phenomenon precisely similar occurs in connexion with shorter periods. If we take inequalities having a period of three or four months we find that such are alternately well developed or of large range and badly developed or of small range, and that a large range of such is accompanied with an exaltation of the base line or line of average efficiency, while a small range is accompanied with a depression of the same. The result is a curve of the base line of which the period is roughly speaking eleven years. May we not therefore imagine that the so-called eleven-yearly period, or, to speak more correctly, the ten and a half and twelve yearly periods into which the eleven-yearly period may perhaps be analysed, may be in reality beat periods for shorter disturbances? Is it not therefore possible that a study of these shorter periods may give us information regarding the nature of the eleven-yearly period, whether for sun-spots or declination ranges, which the small series of actual observations is incompetent to afford?

52. *Declination Range Weather.*—Allusion has already been made to magnetical weather as perhaps having laws similar in some respects to those which regulate meteorological weather. Now the diurnal ranges of magnetic declination and those of atmospheric temperature present us with elements of the two weathers that can easily be discussed. Again there is strong evidence for supposing that an element of meteorological weather, such, for instance, as temperature range, travels as a rule from west to east, so that a peculiar style of temperature range might be expected to appear first in America and some days afterwards in Great Britain. It becomes therefore a question for inquiry whether this travelling from west to east applies also to magnetical weather as evidenced by the diurnal declination range. Stewart is of opinion that this law of travelling applies to both, but that magnetical weather travels faster than meteorological (see *Proc. Roy. Soc.*, January 10, October 23, 1879, and June 9, 1881). From the preliminary discussion made by him it would appear that Kew lags behind Toronto as regards phase of magnetical weather by 1·6 days, that Prague lags behind Kew 0·7 days, and that Trevandrum lags behind Kew by 9·7 days. This conclusion cannot however be regarded as established until it is confirmed by a more complete discussion of observations.

53. *Disturbance Diurnal Variation of Declination.*—Magnetic storms (§ 38) were so named by Baron Humboldt, one of the first observers of such phenomena. From observations at Paris, Berlin, and Freiburg he found that very frequently, though not universally, these three stations were simultaneously affected by such storms. The observation of magnetic disturbances was afterwards pursued in a systematic manner by Gauss and Weber of Göttingen. Term-days were instituted for this purpose by these observers,—that is to say, periods each of twenty-four hours' length during which observations were simultaneously made at intervals of five minutes at Gottingen and about twenty other stations distributed generally over the continent of Europe. Finally, the establishment by the British Government of the colonial magnetic observatories, and the energy and sagacity of their director, Sir E. Sabine, have very greatly increased our knowledge of these remarkable phenomena.

Sabine has not merely separated the disturbed from the undisturbed observations as explained in § 38, but he has divided the former into two categories—(1) those tending to increase westerly declination and either element of force, and (2) those tending to diminish the same He finds that these two categories obey different laws, from which he argues that there are at least two sets of disturbing forces In fact, if we have to give up the idea of a single force of constant type, it is natural to ask if the phenomena of disturbance can be approximately represented as due to the united action of two independent types of force It was probably some such idea that led Sabine to separate disturbances into these two categories above mentioned Here there is no attempt to assert that these two types represent an ultimate and complete analysis of the forces concerned We merely use the separation as the most convenient method at our disposal in the present state of our knowledge for ascertaining whether there be indications of a dual system

---

[1] *Proc. Lit. and Phil. Society of Manchester*, March 8, 1881.

54 *Results in the Northern Hemisphere* —Sabine s method of viewing the phenomena has enabled him to obtain the disturbance diurnal variation for the following stations

Kew	51° 29 N lat	0 8 W long
Peking	39 54 N	116 [illegible] E
Nertchinsk	51 19 N	114 9 E
Toronto	43 40 N	79 0 W
Port Kennedy	72 01 N	94 20 W
Point Barrow	71 21 N	156 15 W

w may be regarded as on one side and Peking and Nertchinsk as probably on the other side of the Asiatic pole, while Toronto may be regarded as on one side and Port Kennedy and Point Barrow as on the other side of the American pole (§ 29) The question as to what influence, if any, these poles have upon the disturbance diurnal variation of declination is thus one which may be answered by examining the results obtained at these various stations For this purpose, instead of recording the aggregate disturbances at the various hours, the result is expressed in ratios,—the mean hourly ratio for the day being taken as unity, or in other words the whole body of disturbances for the twenty four hours being reckoned as twenty four The results of this method are graphically represented in fig 37, where in the left hand curves Kew time is used, and in the right hand curves local time, each starting at 0^h.[1]

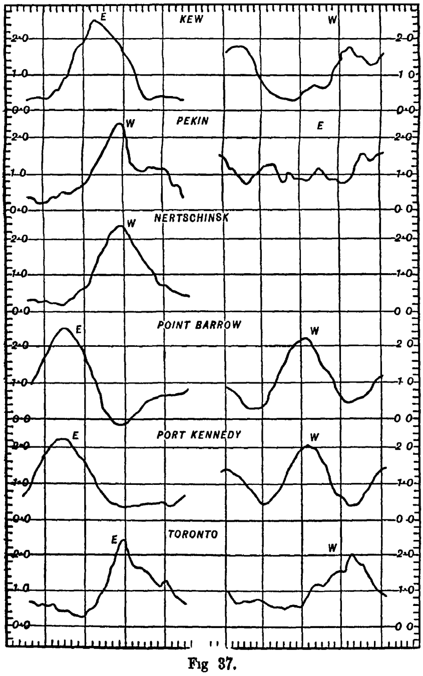


Fig 37.

55 At all the various stations one curve exhibits unmistakably a single progression, while the other exhibits more or less distinctly a double progression At Kew, Toronto, Port Kennedy, and Point Barrow it is the easterly disturbances which exhibit this single progression, while, on the other hand, at Peking and Nertchinsk, stations which are oppositely related to the Asiatic magnetic centre it is the westerly disturbances which do so It is imagined by Sabine and others that this peculiar reversal is due to the fact that Kew and its associated stations may be regarded as on one side and Peking and Nertchinsk as on the other side of the movable magnetic system

Sabine has likewise remarked that the single progression curves, whether denoting easterly or westerly disturbances, exhibit maxima which take place not far from the same absolute time We have therefore plotted the left hand curves according to Kew time, that the eye may readily see the amount of simultaneity which their corresponding phases exhibit It will be noticed that there is a very striking simultaneity between the maxima of Kew, Toronto, Peking, and Nertchinsk, but that the maxima for Port Kennedy and Point Barrow, while both occurring about the same time, fall at a time decidedly if not very greatly different from that of the other maxima Indeed the time of maximum for Port Kennedy and Point Barrow is not far from the time of minimum for the other stations Now it has been noticed by Sabine that Port Kennedy and Point Barrow may be regarded as on one side of the American magnetic centre of intensity, while Toronto and the other associated stations are on the other side It seems therefore possible to connect this last fact with the change in the time of maximum Sabine has likewise remarked that the aggregate amount of disturbances is much greater at Point Barrow than at any other station Now Point Barrow is likewise that spot where auroras are most frequent Thus in the phenomena we are now discussing there is first of all a marked reference to the Asiatic pole, secondly, a reference not so marked, perhaps, to the American pole, and thirdly, a reference to the centre of auroral activity Sabine, whose experience of such matters is very great, appears to think most of the reference of these phenomena to the Asiatic pole He thinks that ' of the two magnetic systems which are distinctly recognizable in the magnetism of the globe one has a terrestrial and the other a cosmical source and that it is "the latter of these two systems which, by its progressive translation, gives rise to the phenomena of secular change and to those magnetic cycles which owe their origin to the operation of the secular change concurring with the conclusion of Walker that "the magnetic influence at any point of the globe is the result of two distinct magnetic systems, the principal of which is the magnetism proper of the globe having its (northern) point of greatest attraction in the north of the American continent, whilst the weaker system is that which results from the magnetism induced in the earth by cosmical action and of which the northern point of greatest attraction is at present in the north of the Asiatic continent Thus the direction of the magnet at any point results from the superposition of these two systems, the nearest pole being always predominant over the more remote (*Phil Trans*, 1868) While disposed to think that something of this nature should be accepted as a working hypothesis, we would, however, point out that the Asiatic pole cannot be regarded as accounting for all the phenomena of disturbances, but that the focus of disturbance is probably nearer the focus of auroras than it is to either of the foci of magnetic intensity

The right hand curves representing these disturbance diurnal variations which have two maxima are, except for Port Kennedy and Point Barrow, decidedly irregular Sabine remarks also that, instead of having a reference to absolute time like those with one progression, their reference is rather to local time We have therefore plotted all these curves according to local time, nevertheless this reference does not come out with very great distinctness but it must be remembered that our analysis of disturbances into easterly and westerly, although, in the hands of Sabine it has given us much new information, has no claim to be regarded as final and complete

56 *Results in the Southern Hemisphere* —Table VIII shows the disturbance diurnal variation of declination exhibited for St Helena, 15° 56 7 S lat, 5° 40 5 W long, Cape of Good Hope, 33° 56 S lat, 18° 28 75 W long, Hobart Town, 42° 52 5 S lat, 147° 27 5 E long

At St Helena and the Cape the easterly disturbances present the appearance of a single progression, while the same remark slightly modified applies to the easterly disturbances at Hobart Town Again the times of easterly maxima for St Helena and the Cape are very nearly simultaneous, while Hobart Town, which we may regard as situated on the opposite side of the chief southern magnetic centre from St Helena and the Cape, has its maximum nearly coincident in absolute time with the minimum of the other two stations It would thus seem that the chief magnetic centre of the south is similar in its action as regards these phenomena to the chief magnetic centre of the north Again the absolute time of single maximum for the south as determined by St Helena and the Cape is about twelve hours different from the corresponding time for the north as determined by Kew, Toronto, Peking, and Nertchinsk. All this is in favour of the working hypothesis already mentioned.

---

[1] If we refer to a paper by C Chambers director of Bombay Observatory (*Phil Trans* 1868) it will be seen that westerly disturbances at Bombay present the same characteristics as westerly at Peking or Nertchinsk the maximum being about twenty-two or twenty-three hours Bombay astronomical time.

Local Astronomical Hours	St Helena		Cape of Good Hope		Hobart Town	
	Easterly Ratios	Westerly Ratios	Easterly Ratios	Westerly Ratios	Easterly Ratios	Westerly Ratios
0	4	2 46	2 1	1 6	1 14	0 65
1	3 17	2 33	2 1	1 2	1 26	0 64
2	2 9	1 88	1 6	1 0	1 32	0 1
3	2 00	1 44	1 0	0 8	1 40	0 6
4	0 89	1 23	0 8	0 7	1 33	0 56
5	0 4	0 56	0 4	0 6	1 32	0 52
6	0 14	0 45	0 4	0 9	1 16	0 72
7	0 05	0 50	0 1	1 2	0 62	1 04
8	0 0	0 41	0 1	1 9	0 40	1 31
9	0 03	0 37	0 2	1 2	0 32	1 79
10	0 07	0 43	0 1	1 1	0 28	1 96
11	0 00	0 42	0 2	0 8	0 74	2 31
12	0 00	0 31	0 3	0 5	0 62	2 05
13	0 00	0 32	0 4	0 6	0 55	1 72
14	0 01	0 24	0 2	0 6	0 63	1 52
15	0 09	0 23	0 4	0 5	0 85	1 26
16	0 00	0 28	0 4	0 4	1 07	0 84
17	0 08	0 24	0 5	0 4	0 87	0 47
18	0 39	0 42	1 0	0 8	1 02	0 44
19	0 87	0 89	1 8	1 2	1 53	0 53
20	1 2	1 52	2 3	1 4	1 8	0 70
21	2 1	1 72	2 3	1 7	1 41	0 55
22	3 08	2 21	2 5	1 8	1 27	0 5
23	2 78	2 60	2	1 7	1 24	0 62

Finally, the westerly disturbances at the three southern stations bear greater marks of a double progression and of irregularity just as they did in the northern hemisphere and moreover like their northern analogues they are regulated by local rather than by absolute time

57 *Distribution of Declination Disturbance over the Various Months of the Year* —Broun was probably the first to remark in reducing the Makerstoun observations that the disturbances were greatest at the equinoxes and least at the solstices His method was to find for each month the mean diurnal inequality, and then to consider the difference of each individual observation from the monthly mean for that hour as a disturbance, the summation of all such differences for the month denoting the monthly disturbance value The following table embodies the results at various stations—those at Toronto, Hobart Town, and the Cape being given by Sabine, and that at Bombay by C Chambers, who has pursued Sabine's method of separating disturbances —

TABLE IX —*Monthly Distribution of Declination Disturbances*

	Toronto		Bombay		Cape of Good Hope		Hobart Town	
	Easterly	Westerly	Easterly	Westerly	Easterly	Westerly	Easterly	Westerly
January	0 55	0 57	0 94	0 88	2 1	1 4	1 62	1 54
February	0 81	0 85	0 89	0 6	1 7	1 3	1 16	1 0
March	0 97	0 89	1 21	0 3	0 7	1 1	1 11	1 11
April	1 23	1 24	1 14	1 29	1 5	1 6	1 26	1 18
May	0 94	0 93	0 57	1 00	0 3	0 9	0 65	0 51
June	0 83	0 55	0 73	0 89	0 3	0 4	0 90	0 59
July	1	1 13	1 16	1 8	0 6	0 6	0 1	0 54
August	1 7	1 17	1 64	1 23	0 4	0 4	0 84	0 3
September	1 6	1 66	1 20	1 04	0 5	0 9	1 29	1 0
October	1 12	1 17	1 52	1 31	1	1 0	1 22	1 27
November	0 0	0 88	0 40	0 41	1	1 0	0 73	0 9
December	0 0	0 98	0 68	0 3	1 2	1 2	1 29	1 23

58 A careful inspection of this table without attempting a more complete analysis, will it is thought lead to the following conclusions —

(1 Although for any station the distribution of the easterly disturbances over the various hours of the day is generally different from that of the westerly yet the same law of distribution over the various months of the year is followed by the easterly and by the westerly disturbances at any station—the law at one station being, however different from that at another

(2) In all stations there is first an annual inequality exhibiting a maximum generally a short time after the summer solstice with a corresponding minimum for the winter solstice and secondly a semi annual inequality exhibiting a maximum generally a little after each equinox

(3) The equinox maximum is very conspicuous at Toronto but the summer maximum is most conspicuous at the other stations

59 In § 38 it was observed that the observations set down as disturbed at any station may nevertheless be a mixture of what may be termed true disturbances and of the more prominent specimens of magnetic weather The truth of this statement would appear to be borne out by the laws now given In one of these we find that disturbances, at all stations, have a maximum about the time of the summer solstice and a corresponding minimum about the time of the winter solstice But the absolute time of the summer solstice for stations north of the equator corresponds with that of the winter solstice for stations south of the line It would therefore appear that in so far as this law is concerned such disturbances lack the element of simultaneity On the other hand, a law of this nature would naturally hold for magnetic weather For at any station the diurnal range of declination is greatest at the summer solstice, and hence any considerable proportional variation of this would, if represented by a fixed scale, present the appearance of being greatest likewise at this time The question thus arises whether this law does not rather apply to magnetic weather than to real disturbance

Again the semiannual inequality of disturbance exhibits through out the globe a maximum at the equinoxes, and thus presents the element of simultaneity which was wanting in the annual This law may therefore refer to true disturbance, and this view is supported by the fact that the aurora—which may be regarded as the universal accompaniment of great and simultaneous disturbances—obeys, as we shall afterwards see, in those stations where it has been well observed, this very same law, that is to say, it has like wise maxima at the equinoxes

60 *Distribution of Declination Disturbances over Various Years.* —In 1852 Sabine discovered (*Phil Trans*, 1852, p 103) that disturbances have a long period inequality allied to that of sun spots in such a way that a maximum and a minimum of disturbance coincide with a maximum and a minimum of sun spot frequency.

This will be seen from the following table (X), in which we have the relative values of declination disturbance at Toronto and Hobart Town compared with the number of groups of spots observed on the sun's disk —

	Values of Declination Disturbance		Groups of Sun Spots
	Toronto	Hobart Town	
1843	0 55	0 48	34
1844	0 73	0 82	52
1845	0 62	0 67	114
1846	1 26	1 03	157
1847	1 40	1 44	257
1848	1 43	1 60	330

61 The following table (XI) exhibits the same thing for Bombay The first column of this table is derived from the magnetic results of C Chambers, while the sun spot areas are those of Messrs De la Rue, Stewart, and Loewy

	Aggregate Values (in Minutes) of Declination Disturbances	Sun Spot Areas
1859	1532 1	1352
1860	1421 6	1313
1861	951 8	1297
1862	1240 5	1211
1863	691 1	676

We may conclude from these tables that declination disturbances march with sun spots, but that the alliance between these two phenomena is probably not so intimate as that between declination ranges and sun spots

62 *Distribution of Declination Disturbances over the Surface of the Globe* —It is well known that disturbances are comparatively small near the equator while they are great near the magnetic poles and greatest of all perhaps near the position of maximum auroras If we adopt Sabine's system of separating disturbed from undisturbed observations, it is thus clear that the same separating value cannot be adopted at all stations At first sight this would seem to introduce an element of uncertainty in the estimation of disturbances, but it was soon found by Sabine that no very great nicety is required in this matter Not only do the laws which regulate disturbances at a given station remain comparatively unaffected by the magnitude of the separating value but it is likewise easy to tell whether the aggregate disturbance value at one station is decidedly greater or less than at another Probably at present it would be impossible to obtain more definite information than this

63 The following table (XII) exhibits the proportion between the aggregate amount of easterly and that of westerly disturbances of the declination at various stations in both hemispheres —

Name of Station	Easterly	Westerly
Toronto	1 40	1
Point Barrow		
Port Kennedy		
Carlton Fort		
Kew	1 19	1
Peking	1	1 21
Bombay		
St Helena		
Cape of Good Hope		
Hobart Town		
Falkland Isles	1 66	

64. *Annual Variation of Declination.*—The declination fluctua-

tions of short period hitherto discussed are not necessarily accompanied by a permanent change of mean position of the needle We have now to inquire whether there be any fluctuations of long period (besides the secular change discussed in §§ 30–33) tending to alter perceptibly the position of the magnetic needle This leads us at once to the annual variation, for our knowledge of which we must look to the later made and more accurate observations, in which all possible sources of error have been carefully eliminated Broun has made an exhaustive experimental inquiry into the various sources of error which could possibly influence his declination needle at Trevandrum His conclusion was that the variations of torsion of a well made thread are not sufficient to produce a sensible effect upon the position of a powerful magnet In fact Grubb s magnet, weighing 6000 grains, and Adie s, weighing 1100 grains, give almost identical results We may extend these conclusions to other observatories where well devised instruments have been established, and look with much confidence to such instruments registering correctly the secular as well as the annual change of declination that may be taking place at each locality

65 The following table (XIII), borrowed, with the exception of the Trevandrum and Bombay results, from E Walker s *Terrestrial Magnetism*, shows the annual variation at seven stations —

	Mean Declination	Mean Annual Secular Change	Observation Years
Kew	21 39 W	7 39 00 E	1858–62
Hobart Town	9 6 E	1 23 20 W	1844–48
St Helena	23 27 W	7 57 00 W	1841–45
The Cape	29 7 W	0 29 40 W	1841–46
Toronto	1 35 W	1 57 12 W	1845–51
Trevandrum	0 35 E	1 3 4 E	1854–69
Bombay	0 31 E	3 1 0 E	1859–65

TABLE XIV —*Showing the Mean Annual Variation for each Month of the Year at Seven Stations*

	Kew	Toronto	St Helena	Cape of Good Hope	Hobart Town	Trevandrum		Bombay
						Grubb	Adie	
	"	"	"	'	'	"		
April	+ 1 5	− 0 6	− 2 4	+64 2	−22 2	+ 1 2	+ 6 8	+11 0
May	−41 8	− 9 6	− 1 2	−10 9	− 8 7	+ 3 4	+ 8 7	+10 3
June	−50 6	−17 4	−13 8	−62 4	−34 1	+ 5 6	+ 8 7	+ 9 8
July	−70 3	−42 6	+ 8 4	−58 2	−20 6	+ 1 6	+ 2 2	+ 1 7
August	−20 7	− 4 2	− 3 6	−61 8	−12 9	− 2 8	− 3 2	+ 1 6
September	+ 9 8	+47 4	−19 8	−43 2	− 4 5	− 8 7	−10 5	+ 0 4
October	+49 6	+61 0	+ 1 8	− 4 8	+13 6	− 8 0	−11 1	− 8 9
November	+34 8	+24 6	+ 7 2	+25 2	+27 6	+ 1 2	− 3 0	+ 1 2
December	+39 6	+19 8	+ 7 2	+42 6	+38 5	+ 3 3	− 1 3	−18 2
January	+ 2 6	+ 4 2	− 3 0	+29 4	+32 9	+ 7 1	+ 3 2	−10 9
February	+34 2	+ 0 6	+18 0	+43 2	+ 7 9	+ 2 3	+ 2 6	+ 3 1
March	+29 8	− 7 8	+10 2	+49 8	+16 7	− 4 9	− 1 2	− 7 0

Here + indicates that the marked pole of the needle is to the west and − that it is to the east of its mean position for the year

66 To cancel the irregularities of this table let us take the means from April to September and from October to March, the former embracing the months around the June solstice and the latter those around the December solstice (Table XV) —

	Means from April to September	Means from October to March
	"	"
Kew	−28 7	+31 8
Toronto	− 4 5	+17 1
St Helena	− 5 4	+ 6 9
Cape of Good Hope	−28 7	+30 9
Hobart Town	−18 7	+17 3
Trevandrum	+ 2 1	− 1 6
Bombay	+ 0 8	− 0 8

It will be seen from the above that the means for Trevandrum and Bombay present opposite signs to those for the other stations The whole amount for Trevandrum is no doubt very small, and Chambers does not regard the evidence for Bombay as conclusive, but on the whole it would appear that two observatories near one another present evidence of a similar behaviour in declination, and we are therefore disposed to regard it as a reality

67 *Semiannual Variation of Declination* —If we look at the numbers of Table XIV , we shall see that there are traces of turning points at the equinoxes Let us, in order to exhibit this, compare together the sums for the six months grouped around the two equinoxes with those for the six months grouped around the two solstices—that is to say, compare the sums for February, March, April, August, September, October, with those for November, December, January, May, June, July—and we thus obtain the following table (XVI) —

	Sums around Equinoctial Months	Sums around Solstitial Months
Kew	+104 2	−85 7
Toronto	+ 96 4	−21 0
St Helena	+ 4 2	+ 4 8
Cape	+ 47 4	−34 2
Hobart Town	− 0 7	+25 6
Trevandrum	− 11 0	+20 3
Bombay	+ 0 2	− 0 1

68 *Solar Diurnal Variations of the Horizontal and Vertical Components of Magnetic Force* —Although self recording magnetographs have been established in many observatories throughout the globe, yet, owing to the peculiar difficulties of the task, and the labour of the process of reduction, very little has been done towards determining the solar diurnal variation of the horizontal and vertical components of the earth s magnetic force Senhor Capello of the Lisbon Observatory has, however, made progress with his reductions, and has already published valuable information regarding the solar-diurnal fluctuation of the two force elements at his observatory

In his attempts to eliminate the disturbances of horizontal and vertical force by the method of Sir E Sabine, Senhor Capello has experienced considerable difficulty, more particularly with the records of the vertical force magnetograph This instrument and the bifilar have very often been found by him to change their position of equilibrium after strong perturbations Again there is generally, for any hour, a variation at the beginning and end of the month from the monthly normal value for that hour owing to change of temperature, and this cannot be completely corrected inasmuch as the coefficient of temperature is not exactly known These two causes combined tend to falsify the results when the plan adopted is the method of comparison between the individual values of any hour and the normal monthly average of that hour Senhor Capello has found it necessary to select and extract the disturbances, not directly from the hourly values, but by comparing the variation of an individual day with the average diurnal variation derived from the month

To illustrate this method by means of an example let us imagine that the sum of the twenty four hourly values for a particular day is 24,000 and that the average monthly diurnal variation would indicate that a particular hour of this day should have a value 990, then if the value for this hour should prove to be greater or less than 990 by more than a certain amount it would be set aside as a disturbed observation Senhor Capello rather thinks it will be desirable somewhat to modify this method, and he concludes his remarks by observing that for this and other similar questions it is most necessary that directors of establishments possessing magnetographs should agree together to employ the same method in their reductions in order that their results may be comparable with each other With the view of adding weight to these remarks, we may quote the observation of Sir William Thomson, that our ability to analyse mathematically that influence which produces the diurnal variation will depend upon our knowing at a certain number of stations the exact nature of this diurnal variation for each of the three magnetic elements A complete theory of this diurnal influence must therefore wait upon the concerted action of the directors of the various establishments possessing magnetographs

69 *Change in Horizontal Force Range from Month to Month* —Although we do not possess finally accurate determinations of the solar diurnal variations of either element of the force, yet we are in possession of information regarding the change in the diurnal range of the horizontal force from month to month at the Greenwich Observatory William Ellis has given us the following table (*Phil Trans* , 1880) representing the monthly mean diurnal range of horizontal force at that observatory expressed in ten thousandths of the whole horizontal force In the formation of these means, days of great magnetic disturbance were rejected, and also certain other days on which there prevailed a smaller but considerable amount of disturbance estimated according to a general standard formed in the examination of many thousands of photographs

TABLE XVII —*Monthly Mean Diurnal Range of Horizontal Force at Royal Observatory, Greenwich*

May	June	July	Aug	Sept	Oct	Nov	Dec
[illegible]	27 3	27 2	25 2	23 2	19 8	14 3	11 6

Thus, like the declination range (§ 43), the horizontal force range has a maximum in summer and a minimum in winter, and exhibits a tendency towards maxima at the equinoxes

70 *Long Period Inequalities of Horizontal Force Range —Lagging Behind* [1]—Ellis has compared the diurnal range of the horizontal force as well as that of the declination at Greenwich with the period of sun spot frequency, his comparisons extending from 1841 to 1877, and he has deduced the following conclusions —

---

[1] Secchi (*Wolf s Astronomische Mittheilungen*, No 21) seems to have been the first to indicate a relation between the state of the sun s surface and the diurnal variation in the horizontal force

(1) The diurnal ranges of the magnetic elements of declination and horizontal force are subject to a periodical variation, the duration of which is equal to that of the known eleven year sun spot period

(2) The epochs of minimum and maximum of magnetic and sun spot effect are nearly coincident, the magnetic epochs on the whole occurring somewhat later than the corresponding sun spot epochs The variations of duration in different periods appear to be similar for both phenomena

(3) The occasional more sudden outbursts of magnetic and sun spot energy, extending sometimes over periods of several months, appear to occur nearly simultaneously, and progress collaterally

71 *Disturbance Diurnal Variation of Force Components* —We may derive the following conclusions from the results obtained by Sabine for the observatories of Toronto, Kew, and St Helena For each element there are two categories, namely, those disturbances which tend to increase and those which tend to diminish the element in question

(1) At Toronto the disturbances increasing both elements of force well represent single progressions with maxima occurring for both about 4 or 5 hours local time Again the disturbances decreasing both elements represent fairly well single progressions with maxima occurring for both at about 14 or 15 hours local time

(2) At Kew the disturbances increasing both elements represent well single progressions with maxima occurring for both about 5 hours local time On the other hand, the disturbances decreasing the horizontal force represent signs of a double progression and those decreasing the vertical force signs of a single progression, the maximum for the latter falling between the two maxima for the former and occurring at 14 hours local time

(3) There is not the same close correspondence between the progress of the disturbances which tend to increase both elements nor between the progress of those which tend to decrease both elements at St Helena as there is for the other stations, nor is there the same likeness between the numbers for St Helena and those of Toronto or Kew as there is between the numbers of Toronto and those of Kew

72 The fact that the disturbance diurnal variations of the two force elements at Kew are very like each other while neither of them is very like the corresponding declination variation (§ 54) receives confirmation from a visual inspection of the Kew curves In the *Philosophical Transactions* for 1862 Stewart thus describes the result of an inspection of the disturbances of these curves for the years 1858, 1859, 1860 (disturbance years) —

> There are twenty two cases in which the declination is raised or lowered along with the horizontal force and only seven cases of an opposite description Also there are twenty two cases in which the declination is raised or lowered along with the vertical force and only eleven cases of an opposite description Finally there are thirty one cases in which both forces are raised or lowered together and only two cases of an opposite description There is therefore a decided tendency in the curves of all the elements to be raised or lowered simultaneously but this tendency is stronger between the horizontal and vertical force curves than between either of these and the declination It may at the same time be affirmed that with the exception of the disturbance of August to September 1859 there is no very prominent case in which the three elements do not rise or fall together

73 *Peaks and Hollows* —These are certain small but abrupt magnetic changes which from the fact that they generally fall within the separating value are not usually regarded as disturbances These changes can only be brought to light where there is a continuous record of magnetic phenomena such as that derived from self recording magnetographs They were first studied at the Kew Observatory by Stewart (*Phil Trans*, 1862) We have seen that more than one type of force must be concerned in producing magnetic disturbances This is confirmed by the appearance of the Kew records, from which it may be seen that no disturbance of any magnitude is due to the action of a single force varying merely in amount but *not in direction* For if there were only one type of force the distance at any moment of a point in the curve of one of the elements from its normal position should bear throughout a disturbance an invariable proportion to the distance of a corresponding point in the curve of another of the elements from its normal but this is by no means the case

But even if several independent forces are at work it may be thought unlikely that at the same moment a sudden change should take place in all there is thus a probability that sudden changes of force, as exhibited in peaks and hollows, are changes in one of the elementary forces concerned Even if the change is not a very abrupt one, provided that we confine ourselves to such peaks and hollows as present a similar appearance for all the curves, we may suppose that we are observing changes in one only of the elementary disturbing forces, for it is unlikely that two or more independent forces, changing independently, should produce similar appearances in all of the three curves

Assuming it as probable that similarity of appearance in the curve variations of the three elements denotes a simplicity in the disturbing force, Stewart has discussed all such peaks and hollows at Kew extending over the first two years of their production, and has obtained a result which is embodied in the following table —

TABLE XVIII —*Hourly Ratios and Frequency of the Kew Peaks and Hollows, the Vertical Force Disturbance being taken as Unity* [1]

Hour	Declination	Hor Force	Number of Observations	Hour	Declination	Hor Force	Number of Observations
0 1	2 14	2 06	7	12–13	1 76	2 68	3
1– 2	1 97	2 16	7	13 14	2 00	2 04	3
2– 3	1 86	1 99	11	14–15	2 10	2 14	5
3 4	1 81	2 05	7	15 16	2 65	2 11	10
4– 5	1 38	1 73	4	16–17	3 48	2 16	15
5– 6	1 57	1 71	1	17 18	3 80	2 14	22
6– 7			0	18 19	3 94	2 18	28
7– 8	1 82	1 91	2	19–20	3 97	2 25	21
8 9	1 60	2 20	1	20–21	3 41	2 21	23
9 10			0	21 22	3 26	2 30	16
10–11	1 33	3 16	1	22 23	2 7[illegible]	2 00	10
11 12	1 30	2 32	3	23 24	2 30	2 04	13

74 It will be seen from this table that the ratio between simultaneous peaks and hollows of the two components of the force is very nearly constant the horizontal force disturbance being about double that of the vertical force, so far as size on the curve is concerned It will also be seen that there is a very marked diurnal range in the ratio which the declination peak or hollow bears to that of the vertical force, this ratio being greatest about 7 A M About this hour we have also most peaks and hollows, while in the evening and early morning hours there is so great an absence of these phenomena that the ratios are doubtful

75 A preliminary comparison between the peaks and hollows at Lisbon and at Kew has been made by Capello and Stewart (*Proc Roy Soc*, January 28, 1864) with the following conclusions

(1) The Kew peaks and hollows are simultaneously produced at Lisbon in all the elements, but to a smaller extent than at Kew

(2) The direction is the same at both stations for the declination and horizontal force peaks and hollows, but it is reversed in the case of the vertical force, so that a sudden small increase of vertical force at Kew corresponds to a diminution of the same at Lisbon

It would be manifestly impossible to discuss with any advantage the nature and origin of these peculiar changes until more extensive observations of them have been made As the peak and hollow force is probably of a simple nature, a further knowledge of its character may be of much importance to the theory of terrestrial magnetism

It is interesting to remark that we have in peaks and hollows the same close relation between the variations of the two force elements that we find in the larger disturbances

It is believed too that during violent disturbances a certain change of type is produced in the peak and hollow force, and more especially is this remarkable in the great disturbance in August and September 1859, where the declination would seem to march in the opposite direction from the two components of the force We have seen that the same peculiarity characterized on this occasion the larger and more apparent magnetic changes We shall afterwards refer to a circumstance which may perhaps throw light upon this peculiarity (§ 93), meanwhile we conclude by again remarking that during comparative magnetic calms the peak and hollow force shows signs of remaining constant in type, and that it is therefore of great importance that the directors of observatories possessing self recording magnetographs should take united action to observe this force

76 *Other Inequalities of the Disturbance Diurnal Variation of the Force Components* —Sabine has shown that disturbances of the force components present a distribution over the various months of the year very similar on the whole to that which is exhibited by disturbances of declination He has likewise shown that disturbances of the force components present a distribution over various years similar to that exhibited by disturbances of declination Finally, we may probably conclude that disturbances of the force components are smallest at those portions of the earth s surface where disturbances of the declination are smallest, and largest at those portions where such disturbances are largest

77 *Annual and Semiannual Variation of Horizontal Force and Dip* —Broun (*Trans Roy Soc Edin* for 1861) has discussed the results obtained by Sabine at his magnetical stations, and has shown that differential and absolute observations agree in telling us that the horizontal force is smallest at the equinoxes and greatest at the solstices Whipple has recently obtained the same result from the Kew observations

We have deduced the following table (XIX) from the various absolute determinations that have been made at sundry places In it the annual and semiannual variations of declination, horizontal force, and dip are exhibited, "increase" denoting a push to the west, and "decrease' a push to the east The method of obtaining these has already been indicated in §§ 66, 67

---

[1] We ought to mention that with the exception of the one occasion already alluded to, a peak of one element always corresponds to a peak of another element, and a hollow of one element to a hollow of another

Station	Effect on Declination		Effect on Horizontal Force		Effect on Dip	
	At Equinoxes compared to Solstices	At June Solstice compared to December Solstice	At Equinoxes compared to Solstices	At June Solstice compared to December Solstice	At Equinoxes compared to Solstices	At June Solstice compared to December Solstice
Makerstoun or Kew	Increase	Decrease	Decrease	Inappreciable	Increase	Decrease
Toronto	Increase	Decrease	Decrease	Increase	Inappreciable	Decrease
Cape of Good Hope	Increase	Decrease	Decrease	Increase		
Hobart Town	Decrease	Decrease	Decrease	Decrease	Decrease	Decrease
Trevandrum	Decrease	Increase				
Bombay	Undecided	Increase				
St Helena	Undecided	Decrease				

78 In discussing the results of this table we shall assume that the sun acts, and in all probability acts indirectly, upon the magnetic system of the earth This point will afterwards be further examined Meanwhile, assuming this indirect action of the sun, and assuming, to fix our thoughts, that it is in close alliance with the convection system of the earth's atmosphere, we can readily imagine that such solar action would act most strongly on the earth's magnetic poles at the solstices, and that in the June solstice the pole or poles in the northern hemisphere and in the December solstice those in the southern hemisphere would be most affected Now a strong action of this kind upon either magnetic pole may well be presumed to increase the general magnetism of the earth, or at least that portion of it which is most readily affected by external action, that is to say, the induction system Again, if the solar magnetic influence is connected with the convection currents of the earth, we can readily imagine that the influence in the northern hemisphere where there is much land should exceed that in the southern hemisphere where there is much water

If these views be reasonable we might expect two things to follow —(1) the earth's induction system should be stronger at the solstices than at the equinoxes, and (2) it should be more especially strong at the June solstice, when the sun acts in the northern hemisphere We must bear in mind, however, that so vast is the earth that a stimulus applied to its particles most susceptible of magnetism may not be instantaneously propagated throughout its mass, but that time may enter as an element of the question, in which case, inasmuch as the action of the sun at the June solstice is in the northern hemisphere, a station near the south pole may not fully partake of the magnetic effects of this action

79 An hypothesis of this nature would appear to be consistent with the results of Table XIX

In the first place, if the earth should become stronger as a magnet in one or in both of its magnetic systems this would show itself by an increase of horizontal force at least in all such stations as those at which absolute observations are made An influence which increases the horizontal force at these various stations is therefore naturally regarded, and was regarded by Broun, as one increasing the strength of one or both of the magnetic systems of the earth—whether of one or of both will presently appear We may therefore assume from our observations that one or both of the earth's magnetic systems are strongest at the solstices

In the next place we may imagine that the changes of declination and dip which the table exhibits as occurring at the solstices are the very changes which would be wrought in these elements by an increase of power in the earth For we see very well that an increase of horizontal force at the various stations may be regarded as denoting an increase of the earth's magnetic power We cannot, however, see with equal facility what changes would be produced in the declination and dip by an increase in power of one or both of the magnetic systems, but we may well imagine that such changes of these elements as are found to accompany an increase of horizontal force are those that denote an increase of the earth's power

We have thus ascertained the probable nature of those changes of the three elements which denote an increase of power Now it will be noticed from the table that the effect at the June as compared with that at the December solstice is of the opposite nature to the effect at the equinoxes as compared with the solstices,—that is to say, the earth is more powerfully affected in June than in December, the only well established exception to this being Hobart Town in the far south But, assuming that time is an element in the development of this preponderating influence acting in the north, it is easy to see why Hobart Town should not exhibit its full effect

It remains to determine from the observations themselves which of the magnetic systems it is that exhibits these oscillations Analogy would of course point to the induction system, but it is desirable to determine this from the observations themselves

In § 54, when discussing the disturbance diurnal variation of declination, it was found that Toronto and Kew may be regarded as on one side of the Siberian pole, while Peking, Nertchinsk, and Bombay are on the other Now, if it be this pole that is influenced by the oscillations under discussion, we might expect that the influence on declination at Toronto and Kew should be the opposite of that at Trevandrum and Bombay We find by the table that this is the case, and we are thus inclined to attribute these changes to the Siberian instead of the American pole It would thus appear that the observations of Table XIX bear out the provisional working hypothesis which we have ventured to introduce It is quite possible that these remarks may not stand the test of more complete inquiry, but they are here introduced rather as denoting a method of looking at the subject which ought we think to be pursued than as embodying conclusions of a final nature

80 *Effect of the State of the Sun's Surface upon the Absolute Magnetism of the Earth* —We have now to consider whether the state of the sun's surface permanently influences the magnetism of the earth It will at once be seen that any such action will apparently manifest itself as an oscillation in the secular change We must, however, carefully guard ourselves against prematurely concluding that it implies a variation in the amount of true secular change There may be two distinct things—true secular change due to one cause, and action depending on sun spots due to another These, from the nature of the case, are necessarily mixed up together in the yearly changes which we examine, it does not, however, follow that there is any real identity between them We shall now give one example of the method to be pursued in the attempt to detect a solar influence of this nature Let us turn to Table III, and take the declination yearly values at Toronto from 1856 to 1871 Subtracting the value for 1856 from that for 1871, we find that the westerly declination had increased in fifteen years 51 6, that is to say, at the mean rate of 3 44 per annum Again the average declination for the sixteen years 1856 71 is 2° 20 8 corresponding to the epoch at the commencement of the year 1864 Taking the average value and epoch, and also the average yearly increase above given, we are able to construct the following table (XX), in which calculated and observed values at Toronto are compared together —

	Observed	Calculated	Difference
	° ′	° ′	′
1856	1 56 30	1 55 00	+1 30
1857	2 0 50	1 58 44	+2 06
1858	2 4 50	2 1 88	+2 62
1859	2 7 40	2 5 32	+2 08
1860	2 10 60	2 8 76	+1 84
1861	2 14 40	2 12 20	+2 20
1862	2 15 70	2 15 64	+0 06
1863	2 19 10	2 19 08	+0 02
1864	2 21 90	2 22 52	−0 62
1865	2 24 80	2 25 96	−1 16
1866	2 27 60	2 29 40	−1 80
1867	2 29 80	2 32 84	−3 04
1868	2 33 20	2 36 28	−3 08
1869	2 37 10	2 39 72	−2 62
1870	2 41 90	2 43 16	−1 26
1871	2 47 90	2 46 60	+1 30

It may be gathered from this table that the years which correspond to minimum sun spots have in the last column a greater negative or lower positive sign than those which correspond to maximum sun spots, and hence we may conclude that at Toronto the tendency of many sun spots is to increase the westerly declination

81 Performing a similar operation for all those cases in which we have a sufficiently extensive series of observations to work upon, we obtain the following table —

TABLE XXI —*Effect of Numerous Sun Spots on the Values of Magnetic Elements*

Station	Declination	Horizontal Force	Dip
Kew	Increase	Inappreciable	Increase
Toronto	Increase	Increase	Increase
Hobart Town	Increase (*)	Uncertain	Increase
Cape of Good Hope	Decrease		
Trevandrum	Increase		

82 We have good grounds for supposing that the sun is most powerful when there are numerous spots on his surface, and therefore the above table represents a state of things which we may imagine to be caused in one way or another by increased solar power Now the most natural hypothesis is to imagine that an increase of spots acts in producing an increase of disturbances, and that for those stations at which the disturbances tend on the whole to affect the elements in a definite direction there will be left behind a permanent effect in this direction A comparison of Table XXI with Table XII will, however, show that this explanation is not valid. For instance, at Toronto and Kew disturbances tend rather to diminish

than to increase the westerly declination, while the effect of numerous sun spots is to increase it Again at the Cape the tendency of disturbances is to increase the westerly declination, while that of numerous sun spots is to decrease it At Trevandrum again (if we judge of it by Bombay) the effect of disturbances will be to increase the easterly declination, while that of sun spots is to decrease it Again, it is believed that at Kew and Toronto the supposed disturbance effect on the dip agrees in character with the sun spot effect On the whole, therefore there is no definite relation between the two effects

Now if we take Hobart Town, the Cape and Trevandrum in the above table, we find from Table XIV that these stations seem to indicate that the magnetic state of the earth is most powerful at times of maximum sun spots Kew and Toronto, however, so far as declination and dip are concerned, appear to go the other way If, however, we suppose that during the several years of maximum sun spots the American pole as well as the Siberian is affected, and that on such occasions of long continuance the former has more influence than the latter, we shall be able to reconcile our results with the hypothesis of increased solar action We can understand too that time must be an important element in any influence communicated to the American pole, and that, although such influence might be apparent at Toronto and Kew, which are comparatively near the pole, it would not be apparent at the other stations of Table XXI We shall recur to this subject when discussing secular change

VARIOUS PHENOMENA CONNECTED WITH THE SUN AND WITH TERRESTRIAL MAGNETISM

83 *Closeness in Time between Solar Changes and Magnetic Disturbances* —Loomis (*American Journal of Science*, vol 1) has registered the extent of sun spots for the six days preceding and following each of the great magnetic disturbances at Greenwich, and has compared these values with that for the very day of the disturbance In this manner he has treated all the days of great magnetic disturbance at Greenwich for a period of twenty three years, with the exception of those cases in which very few observations of sun spots were made The cases of disturbance thus treated amount to one hundred and thirty five, and the following result has been obtained —

TABLE XXII —*Extent of Spotted Solar Surface*

	Days before Storm						Storm	Days after Storm					
			4	3		1							
Mean of 135 Days	47 9	50 1	54 8	53 5	52 [illegible]	48 [illegible]	5[illegible] 9	49 0	45 1	49 3	4[illegible] [illegible]	45 2	4[illegible] 3

From this result Loomis draws the following conclusions — (1) great disturbances of the earth s magnetism are accompanied by unusual disturbances of the sun s surface on the very day of the magnetic storm, (2) the great disturbance of the sun s surface which accompanies a terrestrial magnetic storm is generally heralded by a smaller disturbance three or four days previous, succeeded by a comparative calm which immediately precedes the magnetic storm

84 There is one instance on record of a sudden solar change which was practically simultaneous with a magnetic disturbance [1] On September 1, 18[illegible]9, a little before noon, R C Carrington was observing by means of a telescope a large sun spot, when, to quote his own words—

> Within the area of the great north group (the size of which had previously excited general remark) two patches of intensely bright and white light broke out I noted down the time by the chronometer and seeing the outburst to be very rapidly on the increase and being somewhat flurried by the surprise I hastily ran to call some one to witness the exhibition with me and on returning within sixty seconds was mortified to find that it was already much changed and enfeebled Very shortly afterwards the last trace was gone and although I maintained a strict watch for nearly an hour no recurrence took place The instant of the first outburst was not fifteen seconds different from 11h 18m Greenwich mean time and 11h 23m was taken for the time of disappearance In this lapse of five minutes the two patches of light traversed a space of about 3[illegible] 000 miles It was impossible on first witnessing an appearance so similar to a sudden conflagration not to expect a considerable result in the way of alteration of the details of the group in which it occurred and I was certainly surprised on referring to the sketch which I had carefully and satisfactorily finished before the occurrence at finding myself unable to recognize any change whatever as having taken place The impression left upon me is that the phenomenon took place at an elevation considerably above the general surface of the sun and accordingly altogether above and over the great group in which it was seen projected
>
> "It has been very gratifying to [illegible] that Mr Hodgson chanced to be observing the sun at his house [illegible] same day and to hear that he was a witness of what he also [illegible] remarkable pl[illegible]

At the very moment when Carrington observed this phenomenon the three magnetic elements at Kew were simultaneously disturbed This disturbance occurred as nearly as possible at 11h 15m A M, affecting all the elements simultaneously, and commencing quite abruptly The first or most abrupt portion of the disturbance lasted only about three minutes for all the elements, but after that there was a more gradual change in the same direction before the curve turned This more gradual continuation of the first sudden movement lasted about seven minutes for all the elements This magnetic disturbance was, however, in reality a small one, and was followed by a very great disturbance which took place not many hours afterwards

85 *Simultaneity of Changes of Horizontal Force at Various Parts of the Earth* —We have already (§ 79) alluded to the superiority of the horizontal force in indicating by its changes what is taking place in the magnetic system of the earth If this system be strengthened as a whole we shall no doubt find the horizontal force increased in value at our various stations, while if the earth s power be weakened as a whole we shall find the horizontal force diminished

Broun has discussed this subject at great length in a memoir already mentioned, and has embodied his observations in numerical results from which the following table has been extracted —

TABLE XXIII —*Daily Means of Horizontal Force at Makerstoun*, (M), *Trevandrum* (T), *Singapore* (S), *and Hobart Town* (H)

1844	M	T	S	H	1844	M	T	S	H
March 1	21 40	07 42	16 40	16 46	March 17	21 30	11 54	19 74	19 12
" 3	18 34	05 25	14 18	13 [illegible]	" 18	20 11	07 [illegible]2	17 65	17 08
" 4	16 53	06 42	14 5[illegible]	14 49	" 19	21 73	08 55	16 26	13 59
" 5	11 43	04 43	12 79	10 04	" 20	22 00	07 83	17 24	16 20
" 6	13 94	01 8[illegible]	10 42	9 66	" 21	23 15	09 06	18 35	17 06
" 7	12 99	04 12	12 87	9 98	" 22	22 47	08 14	18 35	19 12
" 8	16 94	03 81	13 62	11 50	" 24	22 30	09 58	18 76	18 99
" 10	19 12	04 33	14 87	14 07	" 25	23 71	10 69	18 76	19 25
" 11	17 64	05 87	14 87	13 97	" 26	25 22	09 48	20 29	20 10
" 12	18 0[illegible]	06 28	15 01	14 27	" 27	22 24	10 81	18 63	19 33
" 13	23 25	09 58	17 [illegible]	1[illegible] 18	" 28	22 16	07 52	17 79	1[illegible] 73
" 14	23 66	10 61	18 90	17 81	" 29	5 9	03 0	11 54	7 82
" 15	22 12	10 09	18 63	16 85	" 31	17 06	02 27	11 81	10 27

This table shows a considerable likeness between the daily changes of the horizontal force at the four stations For instance, we have a minimum which occurs on March 5 at Makerstoun and March 6 at the other stations, we have likewise a well defined maximum occurring at all stations on March 14, and another occurring at Trevandrum on March 25, and at the other stations on March 26 Finally we have a well defined minimum occurring at Trevandrum on March 31, and at the other stations a day earlier

Broun has extended a similar treatment to daily means for every hour, and fig 38 conveys a good idea of the amount of simultaneity which obtains in the changes of such values of horizontal force at stations far apart

86 *Recurrence of Disturbances at Intervals of about Twenty-six Days* —Broun[2] and likewise Hornstein[3] have observed that there is a tendency in large magnetic changes to recur at intervals of about twenty six days At first it was natural to suppose that we have here a magnetical indication of the true time of the sun s synodical rotation, the interval between two disturbances denoting that which elapses between two presentations to the earth of a peculiarly powerful solar meridian It seems unlikely, however, that there is a really permanent one sidedness of this kind in our luminary, but the result of observation seems to show that for a limited period, say two or three years, certain meridians of the sun appear to be peculiarly powerful The cause of this we shall not here discuss, but simply treat the phenomenon as a fact derived from observation Broun in his paper above quoted (*Phil Trans*, 1876) makes the following remarks —

> We have seen that when one side of the sun is presented to the earth the magnetic force of the latter is greater than when the other side is turned towards us we may even say that the intensity is greatest for a given solar meridian, this however, may be simply an integral effect resulting from the actions due to all the meridians But can we suppose when a great and sudden increase or diminution of the earth s magnetic force occurs that this is produced by some change occurring on a particular solar meridian? This does not seem at all improbable
>
> In order to examine the facts all the cases were noted during the years 1844 and 1845 in which the daily mean horizontal force diminished one thousandth of its whole value within an interval of three days they were found to be twenty eight in number If we call the solar meridian presented to us on the 1st January 1844 the zero meridian (0) and consider the time of rotation to be twenty-six days and that there are twenty six meridians we find that the solar meridians presented to us when these great movements occurred may be arranged in a few groups as in the following table' [Table XXIV p 177]
>
> An examination continues Broun of this table will show that nearly half of the great changes began when the eighth meridian after the zero had passed, while five began near the twelfth after, and five near the zero itself If any doubt existed as to the possibility of these being mere accidental coincidences, it would be removed I think by a consideration of the marked succession occurring between July 31 (No 18) and December 11 1845 (No 28) If we neglect the two cases of July 31 and August 26, which commence at +6 and +5 respectively, we have five cases of successive solar rotations in which the diminutions of intensity began on the +8 day This exact recurrence at the end of twenty six days of a marked diminution of force proves it seems to me that the actions are all due to the sun whose time of rotation must be nearly twenty six days
>
> An examination will show that the sudden diminutions of terrestrial magnetic force are in nearly every case preceded by a sudden increase

In the above extract we have given the author s exact words, but, while thinking with him that these actions are due to the sun, it does not appear to us to follow that the time of the sun's rotation must be nearly twenty six days This assumes that the meridian of peculiar power is fixed on the solar surface It does not, however, seem impossible to imagine that such a meridian may have a proper motion of its own, and indeed the planetary hypothesis of the origin of sun spots would rather lead to this conclusion But if this be the case we shall be unable to deduce from recurrent magnetic disturbances the true value of the period of solar rotation

---

[1] *Phil Trans*, November 21, 1861

[2] *Phil Mag* August 1858 *Phil Trans* 1876

[3] *Vienna Acad S* June 15 1871

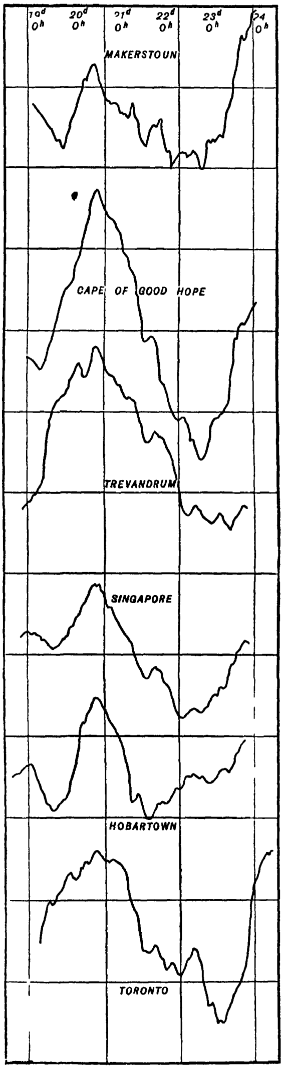


Fig 38

87 *Repetitions of Magnetic Changes* —J B Capello, director of the Lisbon observatory (*Proc Roy Soc.* October 1868), has remarked that at periods of disturbance there are nearly synchronous movements of the declination needle during corresponding hours for two, three, or more days. He thus describes these phenomena —

> [illegible] rallel [illegible] ents, others [illegible] ther periods of repetition of some hours in duration The repeated periods are not entirely similar their phases being so modified that in some cases their identity can only be recognized by a very minute investigation The same periods when repeated have not always the same total duration, nor do they recommence at the same precise hour but sometimes earlier [illegible] the differ [illegible] varying [illegible] m a few [illegible] nutes [illegible] e hour [illegible] also see that the greatest number of repetitions belong to the night hours that is to say those hours [illegible] n the m[illegible] ents of the [illegible] easterly [illegible] morning hours there do not appear to be any well marked repetitions There are twenty four examples now given fifteen of which show repetition on two days, eight on three days and only one where the curve appears repeated for four days It appears that all the facts exhibited in the [illegible] s agree with the cosmical theory the cause (existing in the sun or in space) appears to continue sometimes during two three or several days with [illegible] ergoing remarkable [illegible] nsformation The [illegible] petition, being sometimes earlier sometimes later seems also to indicate that the cause possesses a proper movement the cause persists, but only comes again into operation when the earth by its diurnal rotation is placed in a similar position or conjunction to that of the preceding days

Stewart, having compared Capello's curves with the corresponding traces of the declination at Kew, found that the Lisbon disturbances are almost invariably reproduced at Kew at the same time, only to a greater extent, and also that the same amount of similarity which the various Lisbon curves exhibit is exhibited in the corresponding Kew curves The strongest point in favour of the hypothesis is, he thinks, "not so much the repetition of a single disturbance as the repetition of a complicated disturbance in most if not all of its sinuosities " Several examples of this occur in the diagrams It would seem that something of the above nature was suspected by Humboldt, the earliest investigator of disturbances Humboldt was astonished to discover the frequency with which nocturnal perturbations occurred, sometimes recurring at the same hour on several successive nights (Walker's *Magnetism*, p 80) We would make two suggestions before dismissing this subject

TABLE XXIV —*Cases in which the Earth's Magnetic Force diminished One thousandth of its Value or more in* 1844 45 (§ 86)

No of Case	Date (Jan 1 1844—0)	Change of Force in Hundred thousandths	Solar Meridians		
			5 to 10	11 to 14	−3 to +1 and others
1	87 to 89	−300	+8 to +10		
2	110 to 11[illegible]	−104		+11 to +12	
3	141 to 143	−107		+11 to +12	
4	189 to 190	−116	+7 to + 8		
5	213 to 214	−175	+5 to + 6		
6	221 to 222	−1[illegible]		+13 to +14	
7	267 to 270	−115	+7 to +10		
8	273 to 274	−104		+13 to +14	
9	292 to 294	−268	+6 to + 8		
10	323 to 325	−150		+13 to +14	
11	361 to 364	−1[illegible]			−3 to 0
12	373 to 375	−210	+9 to +11		
13	383 to 385	−1[illegible]			(−6 to −4)
14	416 to 417	−118			0 to +1
15	467 to 469	−350			−1 to +1
16	526 to 528	−110	+6 to + 8		
17	570 to 571	−154			−2 to −1
18	577 to 580	−102	+6 to + 9		
19	603 to 604	−101	+5 to + 6		
20	606 to 607	−159	+8 to + 9		
21	632 to 633	−153	+8 to + 9		
22	646 to 648	−126			(−4 to −2)
23	658 to 659	−118	+8 to + 9		
24	668 to 670	−100			(−6 to −0)
25	684 to 687	−100	+8 to +10		
26	696 to 698	−110			(−6 to −4)
27	702 to 703	−201			−0 to +1
28	710 to 712	−122	+8 to +10		

(1) If we imagine that these changes are caused by the solar influence acting vertically on some susceptible region of the earth, then, inasmuch as they occur at the evening or early night hours, this region must lie considerably to the west

(2) The region must also have a proper motion of its own (see Capello's remark) Is it possible that this proper motion is on the whole from west to east,—a motion which we know is pursued by meteorological weather, and in which it is imagined (§ 52) that magnetical weather as defined by us likewise participates?

88 *Comparison of Declination Changes at Stations near each other* —Messrs Sidgreaves and Stewart (*Pro Roy Soc*, October 1868) have compared together certain curves of the Kew and Stonyhurst declination magnetographs These magnetographs are of the same pattern, and it was found that on ordinary occasions the declination traces at both stations were precisely alike This was confirmed by placing the curves the one over the other, when they were found to coincide even in their most minute features In times of disturbance, however, it was found that the motions exhibited by the Stonyhurst curves were greater than those at Kew, and this excess of Stonyhurst over Kew depended not so much on the absolute size of the disturbance as on its abruptness

This feature of the comparison is exhibited in the following table (XXV), in which the excess of Stonyhurst over Kew in scale divisions is compared with the abruptness of the disturbance, this element being measured by the changes occurring in unit of time —

Group I		Group II		Group III		Group IV	
Excess (under 5)	Abruptness	Excess (under 10)	Abruptness	Excess (under 20)	Abruptness	Excess (above 20)	Abruptness
2	5 7	6	4 2	10	5	21	7 3
2	6 4	6	2 6	10	0	25	2 9
−3	4 0	8	6 3	11	7	25	10 7
0	3 1	5	3 3	10	0	20	7 0
0	3 1	8	8 7	10	8	21	6 6
4	2 9	5	3 5	15	6 4	21	11 2
1	1 8	7	6 3	11	4 9	22	9 6
4	3 3	9	4 7	13	7 4	24	7 8
3	5 2	5	4 1				
Means 1 5	3 7	6 6	4 9	11	6 5	22	7 9

It is very desirable that further comparisons of this nature should be made

89 *Auroral Displays* —These are very frequent if not continuous near the magnetic poles, while in middle latitudes they are the invariable accompaniments of all considerable magnetic storms Near the equator they hardly ever occur

There is a considerable variety in the forms assumed by these displays, and it is possible that this may denote a corresponding variety in the cause or causes which give rise to this phenomenon

Loomis (*Smithsonian Report* for 1865) specifies five such varieties (1) a horizontal light like the morning aurora or break of day, (2) an arch of light which frequently extends entirely across the heavens from east to west and cuts the magnetic meridian nearly at right angles —in the polar regions five such arches have been seen at once (3) slender luminous beams or columns well defined and often of a bright light (4 the corona the centre of which is invariably near the magnetic zenith but not always exactly coincident with it and (5) waves or flashes of light

90 Auroras exhibit the same annual variation as magnetic disturbances and are most frequent about the equinoxes—a fact first observed by Mairan Kaemtz in his *Meteorology* gives the following table which is applicable to European auroras

TABLE XXVI —*Monthly Frequency of European Auroras*

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2 9	307	440	312	184	65	87	21	405	497	285	225

Loomis again in the memoir already quoted gives the distribution of American auroras over the various months derived from one hundred and thirteen years observations at New Haven and Boston twenty five years observations at New York and two years observations in Canada His results are represented in the following table —

TABLE XXVII —*Monthly Frequency of American Auroras*

	Boston and New Haven	New York	Canada	Sum
January	81	6	16	173
February	93	86	31	210
March	110	106	24	240
April	104	125	38	267
May	86	83	22	191
June	83	79	17	1 9
July	123	100	21	244
August	10	122	14	238
September	143	131	19	293
October	99	110	27	236
November	115	74	26	215
December	83	60	16	159

It appears from this table that American like European auroras exhibit a maximum of frequency about the equinoxes

91 Since auroras and magnetic disturbances go together it is natural to imagine that we should have great auroral displays in years of maximum sun spots This is found to be the case and in the following table (XXVIII) Wolf's proportional numbers denoting sun spot frequency are compared with the number of auroras witnessed in Europe and America as compiled by Loomis It will be seen from this table that years of maximum auroras coincide very well with years of maximum sun spot

	Sun Spot Number	Auroral Number		Sun Spot Number	Auroral Number		Sun Spot Number	Auroral Number
1 50	83 1	31	1 4	8 0	14	18	136 9	42
1 1	1	30	1 9	3 8	7	18 8	104 1	60
1752	4	17	1 96	1 6	8	1839	83 4	6
175	8 5	1	1 97	6	5	184	61 8	8
1 4	1	11	1 98	4 6	6	1841	8	67
175	9	10	1 9	1	4	1842	23 0	53
1	12	9	1800	1 6	6	1843	13 1	37
1 7	51	7	1801	33 5	6	1844	1 3	39
1 8	4 1	14	18	4	6	184	58	48
175	54 6	1	18 3	70		184	9 6	4
1760	64	3	1804	1 4	14	1847	9 4	6
1761	80 2	22	18	48	14	1848	1 4 9	
1 62	60	19	180	28 4	1	1849	9 4	69
1 63	48 4	16	18 7	11 1	4	1850	6 8	49
1764	3	11	1808	2		1851	63	6
1 6	91 4	8	1809	3 1	1	1852	59 7	67
1 66	14 1		1810	0 0	1	18 3	38	3
1767	3 5	9	1811	1		18 4	1	3
1768	66 8	30	181	4	1	18		20
1 69	103 4	40	1813	1 6	4	1856	1	11
1 0	9	41	1814	1 9		18 7	2	21
17 1	8	24	181	3 2		18 8		37
1772	65 7	26	1816	46 9		1 9	1	0
1773	3	33	181	3		186	94 8	48
1 74	27 4	3	1818	9	11	1861		6
17	8 8	2	181	2	1	1862	1	28
17 6	21 7	28	1820	16	8	18	4 4	29
17 7	92 0	38	1821	6 1	4	1864	4 2	33
1778	1 1	65	182	3 9		1865	1 4	34
1 79	1 4	0	182	6	1	1866	14 7	31
1780	8 2	67	18 4	8 1	1	186	8 8	22
1781	66	7	182	1 2	4	1868	8	32
1782	8	57	18 6	3 0	12	18 9	8	
1783	22	47	18 7	1	17	18 0	1 1 8	
1784	10 3	39	18 8	6 1	1	18 1	11 8	
1785	2	56	182		5	18	9	
1786	81 2	84	18 0	6 0	2	18	6	
1 8	1 8 2	108	1831	5 4	2	18 4	4 1	
1788	133 3	105	183	26	13	18 5	18	
1789	116 9	84	1833	9 4	11	18 6	11	
1790	90 6	68	1834	1	1	1	11 1	
1791	6 6	46	183	0	1	18 8	8	
1 92	9 5	37	1836	119 3	32	18 9	7 7	
1793	47 8	23						

In fig 39 a graphical representation is given of the likeness which subsists between the progress of auroral frequency spot frequency and declination ranges

92 While the results now given leave little doubt as to the fact of a connexion of some sort subsisting between sun spots on the one hand and magnetic disturbances and auroras on the other yet it is desirable to obtain evidence as to the closeness of the connexion between auroras and sun spots similar to that which was exhibited in § 82, and which showed the close connexion in point of time between sun spots and disturbances Loomis has with this view treated auroras in precisely the same way in which he treated disturbances, and has obtained the following table —

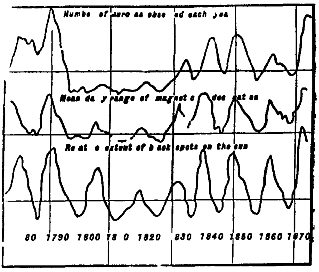


Fig 39

TABLE XXIX —*Extent of Spotted Solar Surface*

	Days before Aurora 6	5	4	3	2	1	Aurora	Days after Aurora 1	2	3	4	5	6
Mean of 251 Days	50 3	52 7	51 0	51 9	53 1	3 7	60 5	54 8	52 5	53 3	51 4	53 3	50 7

From which he concludes that auroral observations in the middle latitudes of America are generally accompanied by a maximum disturbance of the sun s surface on the very day of the aurora

93 *Earth Currents* —These are electrical currents which take place in the moist crust of the earth and were first detected by W H Barlow (*Phil Trans* 1849) At a later period they were systematically observed and studied by C V Walker (*Phil Trans* 1862) They are now continuously recorded by photography at the Royal Observatory Greenwich Earth currents are particularly strong during magnetic disturbances Sir George Airy has graphically compared together certain magnetic disturbances as recorded by the Greenwich self recording magnetographs and the simultaneous earth currents recorded by appropriate galvanometers (*Phil Trans* 1868) and finds it almost impossible to avoid the conclusion that the magnetic disturbances are produced by terrestrial galvanic currents below the magnets The likeness between the two systems of graphical representations is unquestionably very striking But while there is no doubt an intimate connexion between earth currents and magnetic disturbances there is one circumstance which should make us pause before assigning the former as the complete and efficient cause of the latter It is thus indicated by Lloyd [1]—

> When we examine the curves in which Mr Barlow has represented the course of the galvanometric deflexions caused by the earth currents we observe that the regularity of that course is continually interrupted by rapid reciprocating movements in which the needle oscillates from one side to the other of the zero alternately These movements are similar to those of the magnetometers with which we are familiar but they are much more rapid and bear a larger proportion to the regular changes I have selected for calculation the observations made during the six hours commencing at 8 A M on May 29 1848 that being a period of comparative disturbance The sum of the changes of the galvanometer needle during that period on the Derby and Rugby line was equivalent to 571 divisions of the instrument—the mean daily range for the entire week being 11 4 divisions and the ratio=50 The sum of the changes of the Greenwich declinometer during the same period was only 57 minutes the mean daily range being 12 4 minutes In like manner the sum of the changes of the horizontal force was 0158 and the mean daily range 0034 The ratio is accordingly the same for the two magnetic elements and its amount is 4 6 or less than one tenth of the corresponding ratio in the case of the galvanometrical changes We learn therefore that the rapid changes of the earth currents are much greater in proportion to the regular daily changes than the corresponding movements of the magnetometers

We shall return to this subject in a subsequent part of this article

94 *Inequalities in Terrestrial Magnetism caused by the Moon* —Kreil in 1841 was the first to point out that the moon has a small influence on the position of the declination needle and shortly afterwards the same fact was independently discovered by John Allan Broun The more recent observations of Sabine and of Broun but especially those of the latter have thrown much light upon the nature of this action As the lunar influence is not generally large, it is necessary to free the observations from the results of other inequalities and this has been done by the two observers above mentioned The results given in Table XXX have been obtained by Sabine (see Walker s *Magnetism*)

95 Thus (1) the mean effect of the moon upon the declination needle is to cause in each lunar day a double oscillation and Sabine has shown that the lunar influence upon the other magnetic elements is of a similar type (2) The turning points for both hemispheres are in all cases not far removed from the lunar hours

---

[1] *Trans Roy Irish Acad* xxiv 11

TABLE XXX —*Mean Lunar Diurnal Variation in Declination*

Lunar Hour	Kew	Toronto	Peking	St Helena	Cape	Hobart Town
0	− 6 2	−18 9	−4 9	−2 6	+ 8 9	+ 9
1	− 9 6	−16 5	−3 9	+0 9	+ 6 4	+8 3
2	− 8 4	− 9 5	−1 5	−2 2	+ 2 1	+8 5
3	− 2 0	− 0 1	+0 7	−4 2	− 2 6	+6 4
4	− 0 6	+ 9 2	+2 6	−5 1	− 6 5	+7 7
	+ 4 0	+15 9	+3 7	−4 6	− 8 4	−1 6
6	+ 9 0	+18 1	+3 9	−2 3	− 7 9	−5 3
	+11 3	+15 3	+3 0	−0 3	− 4 9	−7 3
8	+ 9 6	+ 8 2	+1 3	+2 6	− 0 3	−7 2
9	+ 4 7	− 0 4	−0 6	+4 9	+ 4 7	−4 3
10	− 0 1	−10 7	−2 2	+6 1	+ 8 6	−1 0
11	− 5 5	−17 3	−3 1	+5 9	+10 6	+3 4
12	− 9 6	−19 4	−2 9	+4 4	+ 5 9	+7 2
13	−11 3	−16 3	−1 7	+1 9	+ 6 7	+9 1
14	− 5 5	− 8 3	+0 2	−0 8	+ 1 8	+8 8
15	− 5 4	+ 1 0	+2 3	−3 1	− 3 5	+6 3
16	− 0 6	+10 8	+4 0	−4 4	− 7 9	+2 1
17	+ 5 1	+17 8	+5 0	−4 4	−10 3	−2 7
18	+ 8 5	+20 2	+4 8	−3 1	−10 1	−6 7
19	+ 9 8	+17 4	+3 [illegible]	−1 0	− 7 3	−5 1
20	+ 8 8	+10 [illegible]	+1 [illegible]	+1 5	− 2 7	−9 1
21	+ 7 4	+ 0 4	−0 8	+2 5	+ 2 4	−6 8
22	+ 2 4	− 9 3	−2 9	+4 4	+ 1 7	−2 8
23	− 1 6	−15 9	−4 1	+4 1	+ 5 2	+1 8

In this table + indicates that the north end of the magnet is to the east and — that it is to the west of its mean position

0, 6, 12, 18 (3) In the northern stations we have a maximum westerly deflexion about the hours 0 and 12 and a maximum easterly deflexion about the hours 6 and 18, while in the southern stations the action is the reverse of this (4) The oscillations would appear to be most decided at those stations, such as Toronto and Hobart Town, that are far removed from the equator

96 *Annual Variation of Lunar Effect* —Broun has recently studied with much success the peculiarities of the lunar influence at Trevandrum, and has obtained some very unexpected results His first result was that the nature of the lunar influence upon the declination needle at Trevandrum depends upon the time of the year, and that the southern type of lunar action predominates at Trevandrum during the winter and the northern type during the summer months If we take the mean of the whole year, then probably the southern type will be found to predominate

97 *Mean Lunar Diurnal Variation during the Day and during the Night* —Broun has shown that the action of the moon on the declination needle at Trevandrum is greater in every month of the year during the day than during the night The following table (XXXI) gives the day and night ranges for the various months and their ratios —

Range	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Day	0 85	0 47	0 49	0 41	0 24	0 36	0 40	0 39	0 31	0 23	0 41	0 69
Night	0 24	0 26	0 23	0 22	0 14	0 11	0 22	0 18	0 21	0 21	0 20	0 23
Ratio	3 6	1 8	2 1	1 8	1 6	3 2	1 9	2 1	1 5	1 1	2 1	3 0

It would appear from Broun s observations that there is difference of type as well as a difference of range

98 *Lunar Diurnal Variation with Reference to the Moon's Distance* —Both Sabine and Broun have shown that this variation is greater for perigee than for apogee Broun has found that the mean ratio of the apogee effect to the perigee effect is as 1 to 1 24 nearly He remarks that ' the ratio of the moon s mean distance from the earth in the half orbit about apogee is to that in the half orbit about perigee nearly as 1 07 is to 1 , as the cube of 1 07 is 1 23 nearly, we see that the mean ranges of the curves for the two distances are in the approximate ratios of the inverse cubes of the moon s distance from the earth, as in the theory of the tides

99 *Lunar Diurnal Variation with Reference to the State of the Sun s Surface* —Kreil in a memoir presented to the Imperial Academy of Science in 1852 considers that the observations at Prague and Milan tend to show the existence of a solar period in the lunar variations Sabine (*Phil Trans* , 1856) has discussed the Toronto observations and also (*Phil Trans* , 1857) the Hobart Town observations with the view of deciding this important point and has come to the conclusion that there is no systematic difference in the lunar variation corresponding to the decennial period of the solar diurnal variation, but merely such casual fluctuations as might be reasonably expected, considering the shortness of the periods which they represent

We have made a preliminary discussion of Broun s Trevandrum observations with the view of throwing a little more light on this subject For this purpose we have taken the ranges of the lunar diurnal variations recorded by him for each month of each year We have in the first place grouped these ranges together into threes, representing quarterly results, and have then compared together these quarterly results for years of small and for years of great sun spot frequency,—assuming the years 1854 56 and 1863 64 to represent the former, and the years 1857–62 to represent the latter We have thus obtained the following result —

TABLE XXXII —*Relation between Lunar Diurnal-Ranges of Declination at Trevandrum and Sun Spot Frequency*

	Great Sun Spot Frequency	Small Sun Spot Frequency
February March April	0 501	0 493
May June July	464	380
August September October	04	419
November December January	641	533

It would appear from this table that such ranges are greater at years of maximum than at years of minimum sun spot frequency Nevertheless the proof is not conclusive inasmuch as associated with such lunar ranges we may have remnants of solar disturbance, the tendency of which might possibly be to increase the apparent range Now such disturbances are more frequent at times of maximum sun spots, and it might therefore be conjectured that this tendency would be to increase the apparent lunar range at such times above the range corresponding to years of minimum sun spots On the whole we are not disposed to think that the evidence already adduced is sufficient to decide this question as a matter of fact either in the one direction or in the other

100 *Variation in the Diurnal Range of Declination depending upon the Age of the Moon* —Capello (*Annals of Lisbon Observatory*, 1876) and Stewart (*Proc Roy Soc* , 1877) have separately found that the range of declination is greatest about the times of new and full moon a result recently confirmed by C Chambers of Bombay The following are the results recorded by Stewart derived from 197 lunations at the Kew Observatory —

TABLE XXXIII —*Variation of Diurnal Range of Declination with Moon s Age (0) denoting New and (4) Full Moon*

Phase of lunation	(0)	(1)	(2)	( )	(4)	(5)	(6)	(7)
Value of range	515	512	499	4 [illegible]	50	508	459	503

101 *Earth Currents caused by Lunar Influence* —Mr Alexander J S Adams (*Nature* March 3, 1881) has made use of a telegraph wire the ends of which were connected with the earth, the one at Cardiff and the other at London He observed the currents on this wire every quarter of an hour from March 28 to April 26 1879 He believes that such are earth currents and that they have a lunar diurnal variation There are during the lunar day, according to this observer, four electrical maxima two positive and two negative, each maximum being divided from the next by a zero or point of no current His results likewise exhibit a regular retardation or lagging of the earth current variations behind the corresponding phase of the moon to the extent of nearly three hours, but these require confirmation from further observations

THE EFFECT OF SOLAR VARIABILITY ON THE METEOROLOGY OF THE EARTH

102 We may learn from the preceding paragraphs that the sun exercises a more powerful influence upon the magnetism of the earth at times of maximum than at times of minimum sun-spots It remains now to find whether a similar variability obtains in the phenomena of terrestrial meteorology For this purpose we may divide the meteorological elements into the four divisions of pressure, rainfall wind and temperature, inquiring in what manner these are affected by solar inequalities

103 *Pressure* —In 1871 Baxendell (*Memoirs of the Lit and Phil Society of Manchester* 1871–72) from an analysis of eleven years of the Radcliffe observations, Oxford, came to the conclusion that in years of maximum sun spots the maximum barometric pressure occurred under north east winds and the minimum under south west, while in years of minimum sun spots the maximum and minimum pressures took place respectively under north and south east winds He came likewise to the conclusion that, besides this difference in distribution of the convection currents of the earth, the forces which give rise to the movements of the atmosphere appear to be more energetic in years of maximum than in years of minimum sun spots

104 A study of the isobaric lines would appear to be the best method of obtaining information upon this important point It is well known that during summer the interiors of large continents have a peculiarly low and the surrounding oceans a peculiarly high atmospheric pressure, while a disposition exactly the reverse obtains during the winter months All this is no doubt due to solar action, and we might therefore imagine that when the sun is peculiarly powerful these peculiarities of distribution will be found to be increased in prominence, while they will be diminished at times of comparatively weak solar influence

The distribution of pressure has been studied with much success by the Indian meteorologists, including Messrs Archibald, Blanford, Broun, Charles and Frederick Chambers Eliot and Hill and the following conclusion is the result of their labours We may assume that the Indo Malayan region has for the mean of the year a barometric pressure probably below the general average of the earth We might therefore imagine that during years of powerful solar influence this peculiarity would be increased Now these observers have found that in this Indo Malayan region the barometer is abnormally low during times of maximum sun spots Again western Siberia is a district which in the winter season has a pressure decidedly above the average and we should therefore imagine that during years of powerful solar influence this winter pressure should be peculiarly high But this is what Blanford has found in his discussion of the Russian stations to correspond with years of maximum sun spots [1]

Again Frederick Chambers has enunciated the following laws as resulting from his discussion of various meteorological records —

(1) Variations of the sun spot area are succeeded some months afterwards in the Indo Malayan region by corresponding abnormal barometric variations a high barometer corresponding to a minimum of sun spots [2]

(2) This lagging behind is greater for easterly than for westerly stations In other words this like other meteorological phenomena, appears to travel from west to east

We may therefore conclude that the barometric evidence as far as it goes is in favour of the hypothesis that the sun is most powerful at times of maximum sun spots

105 *Rainfall—Heights of Rivers and Lakes*—In 1872 Meldrum of the Mauritius Observatory brought forward evidence showing that the rainfalls at Mauritius, Adelaide and Brisbane were on the whole greater in years of maximum than in years of minimum sun spots Shortly afterwards it was shown by Lockyer (*Nature* December 12 1872) that the same law was observable in the rainfalls at the Cape of Good Hope and Madras

Meldrum has since found that the law holds for a great number of stations including eighteen out of twenty two European observatories with an average of thirty years observations for each The results are exhibited in the following table (XXXIV) —

Name of Observatory	Number of Years of Observation	Excess (+) or defect (−) in maximum Sun Spot years
		Inches
1 St Petersburg	41	+13 08
2 Christiania	31	+19 65
3 Edinburgh	1	+66 85
4 Konigsberg	19	−22 79
5 Berlin	11	+10 95
6 Utrecht	11	+ 0 44
7 Munster	19	+22 02
8 Greenwich	2	+11 3
9 Breslau	53	+49 90
10 Bonn	11	+ 8 90
11 Brussels	41	+13 84
12 Prague	9	+23 7
13 Paris	64	+28 6
14 Vienna	11	+ 9 94
1 Kremsmunster	41	−18 3
16 Nicolaieff	11	+ 6 44
17 Geneva	41	− 6 16
18 Milan	39	−11 91
19 Rome	18	+18 30
20 Lisbon	11	+ 5 05
21 Palermo	41	+ 4 5
22 Athens	11	+10 86

It would however appear from the observations of Governor Rawson that the rainfall in Barbados forms an exception to this rule being greatest about the times of minimum sun spots

106 Gustav Wex in 1873[3] showed that the recorded depth of water in the rivers Elbe Rhine Oder Danube and Vistula for the six sun spot periods from 1800 to 1867 was greater at times of maximum than at times of minimum sun spot frequency These conclusions have since been confirmed by Professor Fritz [4]

Quite recently Stewart (*Proc Lit and Phil Soc of Manchester*, 1882) has treated the evidence given by Fritz as regards the Elbe and Seine in the following manner He divides each sun period without regard to its exact length into twelve portions and puts together the recorded river heights corresponding in time to similar portions of consecutive sun periods He finds by this means residual differences from the average representing the same law whether we take the whole or either half of all the recorded observations and whether we take the Elbe or the Seine The law is that there is a maximum of river height about the time of maximum sun spots and another subsidiary maximum about the time of minimum sun spots There is some reason too to think that the Nile and Thames agree with those rivers in exhibiting a maximum about the time of maximum sun spots and a subsidiary maximum about the time of minimum sun spots, only their subsidiary maximum is greater than it is for the Elbe and Seine

107 In 1874 G M Dawson came to the conclusion that the levels of the great American lakes were highest about times of maximum sun spots In this investigation the value of the evidence derived from rivers and lakes is no doubt greater than that derived from any single rainfall station inasmuch as in the former case the rainfall of a large district is integrated and irregularities due to local influence thus greatly avoided

108 Dr Hunter, director general of statistics in India, has recently shown (*Nineteenth Century* November 1877) that the recorded famines have been most frequent at Madras about the years of minimum sun spots—years likewise associated with a diminished rainfall

109 *Winds and Storms*—Meldrum of the Mauritius Observatory found in 1872, as the result of about thirty years observations, that there are more cyclones in the Indian Ocean during years of maximum than during years of minimum sun spots [5] The connexion between the two is exhibited in the following table —

TABLE XXXV —*Comparison of the Yearly Number of Cyclones occurring in the Indian Ocean with the Yearly Number of Spots on the Sun*

Character as regards Sun Spots		Number of Hurricanes	Number of Storms	Number of Whole Gales	Number of Strong Gales	Total Number of Cyclones	Number of Cyclones in Max and Min Periods
Max	1847	5	0	0	0	5	23
	1848	6	2	0	0	8	
	1849	3	2	3	2	10	
	1850	4	3	1	0	8	
	1851	4	2	1	0	7	
	1852	5	0	3	0	8	
	1853	1	1	5	1	8	
Min	1854	3	1	0	0	4	13
	1855	3	2	0	0	5	
	1856	1	0	2	1	4	
	1857	2	1	1	0	4	
	18 8	3	1	3	2	9	
Max	1859	3	2	6	4	15	39
	1860	7	4	2	0	13	
	1861	5	2	2	2	11	
	1862	4	2	2	2	10	
	1863	5	2	1	1	9	
	1864	2	2	1	0	5	
Min	1865	2	2	3	0	7	21
	1866	1	4	2	1	8	
	1867	0	4	2	0	6	
	1868	3	2	2	0	7	
Max	1869	3	1	3	2	9	31
	1870	2	1	5	3	11	
	18 1	3	2	3	3	11	
	18 2	6	5	1	1	13	
	1873	4	5	3	0	12	

Up to May 31

In 1873 M Poey[6] found a similar connexion between the hurricanes of the West Indies and the years of maximum sun spots. He enumerated three hundred and fifty seven hurricanes between 1750 and 1873 and stated that out of twelve maxima ten agreed

110 In 1877 Mr Henry Jeula, of Lloyd s and Dr Hunter found that the casualties on the registered vessels of the United Kingdom were 17½ per cent greater during the two years about maximum than during the two years about minimum in the solar cycle

111 *Temperature*—Baxendell, in a memoir already quoted, was the first to conclude that the distribution of temperature under different winds like that of barometric pressure is sensibly influenced by the changes which take place in solar activity. In 1870 Piazzi Smyth published the results of an important series of observations made from 1837 to 1869 with thermometers sunk in the rock at the Royal Observatory, Edinburgh He concluded from these that a heat wave occurs about every eleven years, its maximum being not far from the minimum of the sun spot cycle Sir G B Airy has obtained similar results from the Greenwich observations In 1871 E J Stone examined the temperature observations recorded during thirty years at the Cape of Good Hope, and came to the conclusion that the same cause which leads to an excess of mean annual temperature at the Cape leads equally to a dissipation of sun spots Dr W Koppen in 1873 discussed at great length the connexion between sun spots and terrestrial temperature, and found that in the tropics the maximum temperature occurs fully a year before the minimum of sun spots, while in the zones beyond the tropics it occurs two years after the minimum The regularity and magnitude of the temperature wave are most strongly marked in the tropics

112 The evidence now given appears at first sight to be antagonistic to that derived from the other elements both of magnetism and meteorology, and to lead us to conclude that the sun heats us most when there are fewest spots on its surface This conclusion will not, however, be strengthened if we examine the subject with greater minuteness

---

[1] *Nature* November 25 and December 2 1880

[2] *Nature* March 18 1880

[3] *Ingenieur Zeitschrift* 1873

Ueber die Beziehungen der Sonnenflecken Periode zu den Magnetischen und Meteorologischen Erscheinungen der Erde Haarlem 1878

[5] *Br Assoc Reports* 1872

[6] A Poey *Sur les Rapports entre les Taches Solaires et les Ouragans des Antilles de l Atlantique Nord et de l Ocean Indien Sud*

Scientifically we may regard the earth as an engine of which the sun is the furnace the equatorial regions the boiler, and the polar regions the condenser Now this engine may be supposed to work in the following manner Hot air and vapour are carried along the upper regions of the atmosphere from the equator to the poles by means of the anti trade winds while in return the cold polar air is carried along the surface of the earth from the poles to the equator, forming what is known as the trade winds Whenever the sun's heat is most powerful both trades and anti trades should be most powerful likewise But we live in the trades rather than in the anti trades—in the surface currents, and not in the upper currents of the earth's atmosphere When, therefore the sun is most powerful is it not possible that we might have a particularly strong and cold polar current blowing about us? The same thing would happen in the case of a furnace fire the stronger the fire the more powerful the hot draught up the chimney, the more powerful also the cold draught from without along the floor of the room It might thus follow that a man standing in the furnace-room near the door might be chilled rather than heated when the furnace itself was roaring loudest In fact temperature is a phenomenon due to many causes Thus a low temperature may be due (1) to a deficiency in solar power, (2) to a clouded sky, (3) to cold rain, (4) to cold winds (5) to cold water and ice (6) to cold produced by evaporation (7) to cold produced by radiation into space Blanford has recently shown that at certain Indian stations a low mean temperature occurs when there is an unusually large rainfall and a great amount of clouds a result in accordance with the conclusions previously enunciated by Professor Piazzi Smyth Records of maximum and minimum temperature must not therefore be too closely associated with a maximum and minimum of solar power

113 Considerations of this nature have induced Stewart to imagine (*Nature*, June 16, 1881) that the true connexion between sun spots and terrestrial temperature is more likely to be discovered by a study of short period inequalities of sun spots than by that of the eleven year period in which there is time enough to change the hygrometric state of the atmosphere and the whole convection system of the earth He has accordingly discussed at some length two prominent sun spot inequalities of short period (about twenty four days) and endeavoured to see in what way they affect terrestrial temperature From this it appears that a rapid increase of sun spots is followed in a day or two by an increase of the diurnal temperature range at Toronto Now an increase of diurnal temperature range most probably denotes an increase of solar energy and we are thus led to associate an increase of solar heat with a large development of spots This, however, is a point which requires further investigation

114 *General Conclusion* —On the whole we may conclude that the meteorological motions and processes of the earth are probably most active at times of maximum sun spots and that they agree with magnetical phenomena in representing the sun as most powerful on such occasions although the evidence derived from meteorology is not so conclusive as that derived from magnetism

Hypothetical Views regarding the Connexion between the State of the Sun and Terrestrial Magnetism

115 *Principles of Discussion* —In the following discussion we claim only to advance a working hypothesis, with the view of suggesting further inquiries into the subject of terrestrial magnetism It seems therefore desirable that we should limit ourselves to such probable or possible causes as are known to exist and to operate on the earth These various agents or causes will be described, and we shall endeavour to show that converging lines of evidence point in several cases to certain of these as being most likely to produce that particular type of effect which is exhibited in terrestrial magnetism This course will in our view most readily suggest further inquiries with the view of confirming or disproving the various points of this working hypothesis Believing that the introduction of any unknown cause can only be justified when known causes have been found insufficient to account for the phenomena in question, we have not advocated any direct magnetic action of the sun upon the earth We have refrained from this for two reasons —first, because from what we now know of the sun it appears to us unlikely that it should exercise an influence of this nature upon the earth, since a body at a high temperature possessing very strong magnetic properties is unknown to us and, secondly, we shall see further on that such an influence will not explain the best understood magnetic changes nor is there in our opinion any magnetic phenomenon for the explanation of which it appears absolutely necessary to resort to this hypothesis In fine, without presuming to deny the possibility of unknown influences of this nature, it does not appear to us that the time has yet arrived when we are called upon to resort to such as necessary aids to the discovery of further truth

116 *Nature of Solar Variations* —It is quite certain that there is a variability in the visible appearance of the sun's disk, which exhibits sometimes a comparatively large amount of spotted area while on other occasions it is entirely free from spots Now it has been remarked by Thomson that were the sun an incandescent solid its surface would become cool in a few minutes The astonishing property which our luminary possesses of pouring out continuously a vast amount of radiant energy must unquestionably depend upon machinery of great power by means of which fresh hot particles are rapidly brought from the interior to the surface, while those particles which have given out their light and heat are rapidly hurried downwards to be recruited from the great storehouse of heat in the sun's centre In fine, a gigantic system of convection currents of this nature forms the essential condition without which the sun would not be able to continue shining as it does

The mottled appearance of the sun's disk as seen through a telescope denotes no doubt the existence of a vast system of ascending and descending currents, the hot matter rising from beneath being denoted by the brighter portions and the cold matter descending from above by the darker portions of the structure On certain occasions and in certain regions of the sun the scale of these phenomena is greatly increased, and we have a huge up rush of bright and a corresponding down rush of black matter—in fine the well known sun spot with its bright faculous appendages Whenever sun spots are very frequent we should therefore expect the convection system of the sun to be particularly powerful and the great velocity and size of the red flames or the higher portions of the convection system observed around the sun's limb on such occasions confirm us in this supposition And if the convection system of the sun be particularly powerful when there are most spots on its surface it would seem to follow that the radiation from our luminary should on such occasions be particularly powerful also The spectroscope leads us to the same conclusion It would appear from the observations of Lockyer and others that at times of maximum sun spots certain definite regions of the sun when examined spectroscopically present all the appearances of a very high temperature

We are unable to confirm these conclusions by direct observations of the sun's heating power Actinometrical determinations have not yet been made with sufficient accuracy and persistence to decide this point experimentally We have, however, evidence of an indirect nature derived from terrestrial magnetism and meteorology all tending to make us think that the sun is most powerful during times of maximum sun spots We have seen that on such occasions the solar influence upon the magnetism of the earth is peculiarly powerful in more than one way and that its influence on meteorology is then peculiarly powerful also although we are not so certain of this latter fact as of the former

We may therefore take it to be most probable that the sun is most powerful at times of maximum sun spots and proceed from this basis to propound the two following questions —in the first place, what is the nature of the solar influence upon terrestrial magnetism? and, secondly, why is this influence so much more easily perceived than certain forms of solar influence upon meteorology?

117 *Diurnal Magnetic Variations—Hypotheses regarding them* —The various speculators on the cause of these phenomena have ranged over the whole field of likely explanations (1) It has been supposed that the sun acts directly as a magnet upon the magnetism of the earth (2) It has been imagined that convection currents established by the sun's heating influence in the upper regions of the atmosphere are to be regarded as conductors moving across lines of magnetic force and are thus the vehicle of electric currents which act upon the magnet (3) Faraday reasoning from his discovery that oxygen is paramagnetic, and becomes weaker in its power when heated, and stronger when cooled, supposed that the sun by heating certain portions of the atmosphere renders them less magnetic while others not subjected to any heating influence are rendered more magnetic The action is equivalent to a displacement by means of the sun of the magnetic matter of the earth and involves a displacement of the lines of force Here too the solar action is associated with the great mass of the atmosphere (4) It has been supposed by Christie and by De la Rive that the heat of the sun produces in the atmosphere and in the earth thermo electric currents which produce the daily magnetic variations It is not easy to perceive how we could have thermo electric currents in the upper regions of the atmosphere, but there is no obvious objection to the generation of such currents in the crust of the earth Thus the first hypothesis has no reference to the atmosphere whatever, the second deals with the upper atmospheric regions, the third with the great body of the atmosphere, while the fourth, as we have ventured to modify it, has reference to the crust of the earth

118 *Discussion of these Hypotheses* —Dr Lloyd and Mr C Chambers[1] have both shown that direct solar magnetic action will not account for the peculiarities of the diurnal magnetic variation Again (§ 48) we have strong evidence that changes in the range of the daily magnetic variation lag behind corresponding solar changes in point of time Now this kind of behaviour is inconsistent with direct magnetic action, and points rather to an indirect magnetic effect caused by the radiant energy of the sun

---

[1] *Proc Royal Irish Academy* February 22 1858 *Phil Trans* 1863.

119. Let us therefore dismiss the hypothesis of direct action and consider that of Faraday. We know both from observations of the declination and horizontal force (*Proc. Roy. Soc.*, March 22, 1877, and *Phil. Trans.*, 1880, p. 541) that the action of the sun in producing diurnal variations of these elements is one and a half times as powerful at epochs of maximum as it is at epochs of minimum sun spot frequency. It is hardly credible that there should be such a great difference on these occasions in the sun's heating effect upon the great bulk of the atmosphere. Meteorologists have never observed such a difference, nor is there any marked corresponding inequality of diurnal temperature range. Meteorological evidence is thus against the diurnal magnetic changes being due to the heating up by the sun of the great mass of oxygen which constitutes the magnetic portion of the earth's atmosphere. Again, as there is a preponderance of hot oxygen in the northern hemisphere during the June and in the southern hemisphere during the December solstice, there ought according to this theory to be a well marked annual variation of the magnetism of the earth, the northern hemisphere being at the same time differently affected from the southern. But there are no traces of such a phenomenon, the annual and semi annual variations which we have already described (§§ 64-67) being of quite a different nature, and none of them very large.

120. Precisely the same objections apply with even greater force to the fourth hypothesis. *It seems impossible to allow that any* heating effect of the crust of the earth caused by the sun can be one and a half times as great at epochs of maximum as it is at epochs of minimum sun spot frequency.

121. We are thus driven by the method of exhaustions to look to the upper regions of the earth's atmosphere as the most probable seat of the solar influence in producing diurnal magnetic changes, and it need hardly be said that the only conceivable magnetic cause capable of operating in such regions must be an electric current. Now we know from our study of the aurora that there are such currents in these regions—continuous near the pole and occasional in lower latitudes. A good deal has been said about the difficulty of imagining a daily set of currents to be generated in regions of such imperfect conductivity, but we shall see by and by (§ 134) that there seems ground for imagining that their conductivity may be much greater than has hitherto been supposed.

122. *Analogies between the Meteorological and Magnetical Systems of the Earth.*—We have in the first place a zone of maximum terrestrial temperature, the middle line of which is nearly coincident not only with the geographical but likewise with the magnetical equator. Again, there are possibly in the northern hemisphere two poles of greatest cold which possibly do not greatly differ in position from those spots which we have called magnetic poles or foci. About the southern hemisphere we have no information.

Furthermore we believe that the hot air is carried from the zone of greatest heat to the place or places of greatest cold by means, no doubt, of the return trades which blow in the upper atmospheric regions. The hot air divides at this zone, one part blowing northwards in the northern and another southwards in the southern hemisphere. Now this zone, from which the anti trades divide, has an annual motion of its own, being found farthest north at the June solstice and farthest south at that of December. Probably too the northern system is strongest in June and the southern system in December. If we now turn to the solar diurnal variation of magnetic declination, we find here also a northern and a southern system (§ 41), the type of the one being antagonistic to that of the other. We find also that the northern system is strongest in June and the southern system in December.

Again, it seems probable from what we have now said that the anti trades, strictly speaking, have reference not to the geographical equator and poles but to the zone of maximum and the poles of minimum temperature. Now, turning once more to the diurnal oscillations of the declination needle, it seems probable that the directions east and west must be interpreted as having a reference not to the geographical but to the magnetical pole (§ 45).

These analogies must be taken for what they are worth. Our object in introducing them has reference to the previous discussion from which we concluded that the magnetic influence of the sun is probably due to currents in the upper region of the atmosphere—the cause of which we were content to leave in abeyance. Now these analogies would lead us to suggest that this cause, whatever it is, may perhaps be found to be related to the convection system of the earth on the one hand and to the magnetic system on the other.

123. *Analogies between Meteorological and Magnetical Weather.*—These remarks are borne out by the further analogy which appears to subsist betwixt what we have termed meteorological and magnetical weather. Let us take the solar diurnal variation of declination. Not only is this variation similar in form to the diurnal variation of atmospheric temperature (§ 37), but the ranges of the two have a similar annual variation. And, as the element of meteorological weather affects the orderly march of the temperature range, just so the element of magnetical weather affects the orderly march of the declination range.

Furthermore, just as temperature range weather progresses from west to east (§ 52), so declination range weather would seem to progress in the same direction as the other (§ 52), although at a greater rate. It will doubtless require a more extended investigation to make us quite sure of this latter point; nevertheless we do not perceive the validity of the objection that is sometimes made to the hypothesis of progress in magnetic weather on the ground that magnetic influences are known to affect all portions of the globe simultaneously. It will, we think, be perceived that in the above statement no supposition whatever is made with respect to the rate of propagation of a magnetic influence through the earth; this may be instantaneous or it may not. It is supposed that we have here a travelling cause of excitement, say a travelling cause of currents in the upper regions of the atmosphere which progresses from west to east and always produces its most marked effect above those regions where it passes—just as the sun itself in passing from east to west produces a magnetic effect the various phases of which travel from east to west with the sun which causes them. We think too that this hypothesis of travelling causes of magnetic change is strengthened by the facts observed by Capello and described in § 97.

124. If, however, the objection made to this hypothesis refers to the fact disclosed by Broun (§ 85) that changes of horizontal force appear to take place simultaneously at distant parts of the earth's surface, *then we think that analogy should lead us not to deny the* possibility of a travelling magnetic excitement, but rather to suggest the possibility of there being some meteorological influence which, like the magnetical one above mentioned, may be found to take place simultaneously at different parts of the earth's surface. Now Broun (*Proc. Roy. Soc.*, May 11, 1876) has given us preliminary evidence for supposing that there are simultaneous barometric variations. For instance, there was a barometric maximum at Hobart Town, Peking, the Cape, St Helena, Makerstoun, Singapore, Madras, Simla, Ekaterinburg, and Bogoslovsk about the end of March or first day of April 1845. There appears to have been a simultaneous increase of the horizontal force of the earth at various stations much about the same time, and there also appears to have been a short period maximum of spots on the solar surface. Broun has likewise registered simultaneous barometric variations at Singapore, Madras, and Simla, for the first three months of 1845. From these it would seem that simultaneous barometric maxima are possibly coincident with rapidly increasing sun spot areas.

Again is it not absolutely certain that if there is a sudden increase of solar power this must mean an increase of heat communicated to the earth, although it may be difficult or even impossible to obtain experimental evidence of such a fact? All these are subjects which require further investigation.

125. *Further Remarks on the Solar Diurnal Variation of Declination.*—In § 24 we have asked how far the action of the solar diurnal force upon a freely suspended magnet is due to currents acting directly upon the magnet and how far to a change produced in the magnetism of the earth. Some light appears to be thrown on this point by the behaviour of the needle at places near the magnetic pole where the dipping needle is nearly vertical. On opposite sides of this locality the declination needle points in opposite directions. Now suppose that we have a set of such needles placed all round this region. It seems a legitimate generalization from the observations described by Sabine (§ 45) to conclude that if we place ourselves above the centre of any of these needles at 8 A.M. and look towards its marked pole, we shall find it in every case deflected towards the right, while if we look towards the same pole at 2 P.M. we shall find it deflected to the left. Now if we imagine that at 8 A.M. there are above these magnets (in the upper atmospheric regions) electrical currents of which the horizontal components form a set of positive currents flowing from the pole on all sides, then by the known laws of such currents the marked pole of all these needles will be deflected towards the right. And if at 2 P.M. the resolved portions of such currents should be flowing towards the pole, then the marked poles of all these needles will be deflected towards the left. It thus appears that this peculiar magnetic behaviour might easily be explained by a hypothetical distribution of currents. And in fact in such regions we have indubitable evidence of the existence of currents in the upper regions of the atmosphere. On the other hand this behaviour could not easily be explained by the hypothesis of some definite temporary magnetic system set up by the solar influence in the earth, for in such a case we should imagine that similar poles of all the needles ought to be deflected towards the pole of this temporary system, which is not the case.

126. Another point for consideration is the possible complexity of the solar diurnal variation. For we may imagine (1) that the sun acts in such a manner as to produce a diurnal variation; (2) it may also act like the moon (§ 94) and produce a semidiurnal variation; (3) these possible actions may be accompanied by induced currents in the upper regions of the atmosphere and in the crust of the earth; (4) it is possible that the sun's rays may affect these variations or some of them in the way in which Broun found that the lunar variation at Trevandrum was affected by the sun. It

was found by him that the lunar action was considerably increased when the sun was above the horizon of the place.

127. We have pointed out (§ 119) that, while there is a marked likeness in many respects between the diurnal variation of declination and that of atmospheric temperature, we have yet no long period fluctuation of the diurnal range of temperature at all comparable in magnitude to the magnetic fluctuations. It does not, however, seem difficult to account for this difference if we imagine that the magnetic fluctuations take their origin in the upper atmospheric regions, while the temperature fluctuations are due to the lower regions of the earth's atmosphere. For, as the sun increases in power from times of minimum to times of maximum sun spot frequency, we may imagine that a continuously increasing amount of aqueous vapour will be taken into the earth's atmosphere.

Now the experiments of Tyndall and others induce us to think that the air would under such circumstances become more and more opaque for certain rays of the sun, and thus a continuously decreasing proportion of the sun's heat would be able to penetrate into the lower atmospheric regions. This latter influence would therefore operate to cloak, perhaps to a considerable extent, the effect of the sun's increasing power, and this may very well be the reason why the temperature range at the earth's surface does not exhibit the same eleven yearly inequality as the declination range.

128. There seems however reason to believe that if we go from long to short period inequalities there is a much greater similarity in the range of the magnetical and the meteorological changes (§ 113). The explanation seems to be that in the short period changes the sun has not time to alter sensibly the constitution of the atmosphere, and hence the proportional increase of effect experienced in the upper atmospheric regions is more nearly the same as that experienced near the surface of the earth.

129. *Magnetic Disturbances.*—There is strong evidence that the most important disturbances break out very nearly simultaneously at widely different parts of the earth, and that they even affect both hemispheres at the same time. Very little, however, is known about the *modus operandi* of the forces concerned in producing such disturbances. For instance, it is not known whether a disturbance permanently affects the magnetic state of the earth, *e.g.*, whether one of the magnetic elements before a disturbance begins is sensibly different in value from what it is after the disturbance has ceased to exist. On the other hand we know (1) that disturbances break out on the very day when there are rapid changes taking place on the sun's surface (§ 83), (2) that they generally begin by momentarily increasing the horizontal force, but that the type quickly changes, so that during most disturbances the horizontal force is diminished (§ 86), (3) that large disturbances take place more particularly about the equinoxes, when, we have reason to believe, the horizontal force of the earth is at a minimum (§ 77). May we not possibly conclude from these habits of action that at times of disturbance the earth is magnetically in a delicate state of equilibrium, perhaps having more magnetism than its surroundings would strictly warrant, and being therefore inclined to part with some, and that a sudden increase of solar activity, tending as such changes probably do at first to exalt the magnetism of the earth, nevertheless destroys its magnetic balance and gives it ultimately the opportunity of parting with some of its magnetism? This can only be regarded as a speculation, inasmuch as we do not know whether or not a disturbance produces any permanent influence upon the magnetism of the earth.

130. *Auroras and Earth Currents.*—There is no doubt that these phenomena denote electric currents in the upper regions of the atmosphere and in the moist conducting crust of the earth. The point in dispute is with respect to the origin of such currents. Some are inclined to regard auroras as peculiar manifestations of atmospherical electricity in high latitudes, while others imagine that such displays are rather of the nature of induced currents generated by small but abrupt changes taking place in the magnetism of the earth. The advocates of the first view do not deny that currents taking place somehow in the upper atmospheric regions will have their conditions modified, to some extent at least, by the inducing influence of magnetic changes. Nor will the advocates of the induction hypothesis be disposed to deny the possibility or even the certainty that displays due to atmospherical electricity and not dissimilar to some kind of aurora take place in some region of the atmosphere. But the first party regard auroras rather as the cause than as the effect of magnetic changes, whereas the advocates of induction regard such displays rather as the effect than as the cause of changes somehow produced in the magnetism of the earth. And here it is desirable to remark that the advocates of the induction hypothesis take for granted the magnetism of the earth and the changes thereof as phenomena for which they do not profess to account, whereas unless we go to some absolutely unknown cause (and this is against our present programme) we must look to atmospherical electricity as likely to throw light upon the origin of terrestrial magnetism. We cannot therefore dispense with regarding atmospherical electricity as an agent which may have played an important part in the development of the present magnetical condition of the earth, but we are yet of opinion that, under the present state of things, the theory which holds by atmospheric electricity must largely be supplemented by the induction hypothesis if it is to explain the peculiarities in type or form of the phenomena which observation brings before us.

131. Professor Tait in his essay on thunderstorms attributes one kind of aurora to atmospherical electricity. Such an aurora is, he believes, the manifestation of almost continuous discharges, like those given by a Holtz machine in a vacuum tube. The cause is condensation of vapour going on very slowly in very large spaces of air. The electricity is due to previous contact of particles of air and vapour. The result is that the air particles in the mixture in time acquire a definite difference of potential from those of vapour,—so that, when the latter aggregate, a misty region well charged is the result, and this discharges to the oppositely electrified air all round.

132. Again, Professor Stokes, without attempting to account for the origin of atmospherical electricity, has produced an hypothesis with the view of explaining the intimate connexion subsisting between auroral displays, earth currents, and magnetic changes on the one hand and outbursts of sun spot activity on the other. His idea is that two somewhat distant atmospheric regions A and B are charged, let us say, with positive and negative electricity respectively. A induces in the ground below it a charge of negative, B a charge of positive electricity. At first things are held in this state. A cannot discharge either through the upper atmospheric regions to B or through the lower regions to the ground beneath it, while B is in a position precisely similar. Presently, however, an increase of the radiative power of the sun is produced. Such an increase would probably imply not merely an increase in general radiation but a particular increase in such actinic rays as are absorbed in the upper regions of the earth's atmosphere. The layer of atmosphere between A and B will therefore greedily absorb such rays, its temperature will rise, and, as is known to be the case for gases, the electrical conductivity of the stratum will be increased. A discharge will therefore ultimately take place in the upper regions between A and B; this will relieve the charges of negative and positive in the ground immediately beneath A and B, and these charges will therefore rush together through the ground, producing an earth current. This earth current will be in the opposite direction from the atmospheric current, and the two will combine to represent, virtually at least, if not absolutely, a closed circuit. This will of course affect the earth's magnetism and produce a disturbance.

133. This hypothesis certainly affords a good explanation of the promptness with which disturbances follow increased solar activity (§ 83). Unless we are to resort to some unknown cause it is difficult to think of any other possible explanation of this fact. Such an explanation appears too to receive corroboration from the fact (§ 97) that the lunar influence on the earth's magnetism as observed at Trevandrum is greater during the day than during the night,—greater possibly too at times of maximum than at times of minimum sun spots. We are therefore disposed to accept this explanation of the way in which increased solar activity produces magnetic disturbance as the best that has been brought forward.

134. This does not, however, decide the disputed point how far these elevated currents are due to atmospherical electricity and how far to induction. The argument against the possibility of induced currents in these regions is derived from experiments with vacuum tubes, such as those recorded by Messrs De la Rue and Muller, which would seem to indicate that enormous differences of potential would be required to produce electrical currents in elevated regions where the atmosphere is very rare.

Indeed, on account of these experiments the measurements of the old observers, who sometimes assigned a height of more than 100 miles to the aurora, have been called in question, and it has been supposed against direct observation that these phenomena must always occur in regions much less elevated. It would appear too that such reasons were influential in determining Professor Stokes to regard the aurora as produced by atmospherical electricity, which, as we know from ordinary lightning, presents us with enormous differences of potential; but it is to be remarked that he has carefully guarded himself against the possibility of laboratory experiments with vacuum tubes not being strictly analogous to that which takes place in the upper atmospheric regions. Now it would appear that recent experiments by Hittorf throw some doubt upon the strictness of this analogy. The high difference of potential required to force the current through vacuum tubes is, according to this observer, due in great part if not entirely to the passage of the fluid from the terminal to the residual air of the tube, so that the potential requisite to pass a current through a tube of double length is not sensibly greater than that required for a tube of single length. The whole subject is one which demands further investigation; meanwhile we are not disposed to assert the impossibility of induction currents taking place in the upper atmospheric regions.

135. Let us now consider whether the form or type of the earth currents observed during disturbances favours the presence of induction to any sensible extent. The remarks of Dr Lloyd already quoted (§ 93), which are confirmed by the Greenwich observations, seem to be decisive in this respect. These may be interpreted in

the following manner In a magnetic disturbance we have frequently a general displacement of the various elements—the horizontal force, for instance now on the curve which represents this slow but considerable displacement a large number of comparatively small but very abrupt changes are superimposed These latter appearances are invariably accompanied by quick and strong alternations from positive to negative of the earth currents while the former slow motion although it may be of large range, hardly appears to have any galvanic equivalent at all This would appear to favour the induction hypothesis, according to which small but abrupt magnetic changes should give rise to strong earth currents alternately positive and negative without reference to the position *of the magnet above or below its normal at the time*

136 Another fact bearing upon this hypothesis is that mentioned in § 88 From this it would appear that on ordinary occasions the curves recording the progress of the declination needle at Kew and Stonyhurst are as nearly as possible identical but on occasions of disturbance the range at Stonyhurst is greater than that at Kew by an amount not apparently depending so much on the magnitude of the disturbance as on its abruptness The introduction of the element of abruptness would appear to be in favour of the mixing up to some extent of induced currents with the phenomena in question

137 Sir George Airy has not been able to detect any resemblance in form between the regular diurnal progress of the magnet and that of the earth currents It seems however possible that the peaks and hollows alluded to in *§ 73 may form an important and integral* part of the daily magnetic movement and there even appears to be some evidence that the diurnal progress of the earth currents bears a nearer resemblance to that of the peaks and hollows than it does to the progress of the smoother curve which is usually held to represent the diurnal variation But this is a question which can only be decided by more prolonged investigations

138 To conclude, there can be no doubt that at times of great magnetic disturbance we have currents in the upper atmospheric regions and in the crust of the earth which, so far as we can see must either be due to atmospherical electricity or to induction, or to a mixture of both The proportions of this mixture can only be decided by further inquiry and by the multiplication of stations where atmospherical electricity and earth currents may be observed It ought to be mentioned that the experience of the Kew observers as far as this extends seems unfavourable to the hypothesis of a connexion between auroras and atmospheric electricity

139 *Lunar Semidiurnal Variation* —From the fact observed by Broun (§ 98) that the moon s magnetic influence is as nearly as possible inversely proportional to the cube of the moon s distance from the earth it is impossible to refrain from associating it either directly or indirectly with something having the type of tidal action but in what way this influence operates we cannot tell Is it possible that the earth currents observed by A Adams (§ 101) are induction currents generated in the conducting crust of the earth by the magnetic change caused by the moon,—inasmuch as these currents were found by him to be strongest in one direction about the lunar hours 3 and 15 when the lunar diurnal magnetic effect is changing most rapidly in one direction (§ 95) while they were found to be strongest in an opposite direction about the lunar hours 9 and 21 when the lunar diurnal magnetic effect is changing most rapidly in an opposite direction ?

140 We might perhaps expect from the analogy of the tides that the sun should possess a semidiurnal magnetic effect similar in type to that of the moon Now Sir George Airy in his analysis of the earth currents observed at Greenwich *Phil Trans*, 1870) during days of tranquil magnetism has detected in such currents a semidiurnal inequality having maxima in one direction at solar hours 3 and 15 while it has maxima in the opposite direction at solar hours 9 and 21 The reference to solar hours in this inequality is thus precisely similar to that which the inequality observed by Adams bears to lunar hours

141 If there are induced currents of this nature in the crust of the earth we might naturally suppose that there will be corresponding currents in the upper regions of the earth s atmosphere and in accordance with the suggestion made by Professor Stokes (§ 132) we might perhaps suppose that these currents will be strongest when the upper atmospheric regions are heated by the sun and thereby rendered better conductors Is it not possible to suppose that the influence of daylight upon the lunar magnetic effect discovered by Broun (§ 97) may be due to this cause and may it not also induce us to recognize the possibility of a maximum lunar influence (§ 99) at times of maximum sun spots when there is reason to believe that solar radiation is most powerful ?

142 *Secular Variation* —Sabine and Walker are agreed in regarding this variation as cosmical in its origin and they are apparently of opinion that it is caused by some change in the condition of the sun It seems difficult if not impossible to attribute it to anything else, since the terrella of Halley cannot be now regarded as having a physical existence Again it is more than possible—it is probable—that there are solar variations of much longer period than eleven years On the other hand the evidence given in § 81, tending to show that an access of sun spots produces a change in the magnetic state of the earth consistent with the hypothesis that the magnetizing power of the sun has then been augmented, requires to be confirmed by more observations, and even then it is certain that this magnetic change produced by a considerable change in spotted area is extremely small We cannot therefore regard the very large secular magnetic change as due to a non cumulative magnetic influence of some long continued solar variation, nor does it seem possible to attribute the change to solar influence at all unless we regard this influence as producing results of a cumulative nature

It is possible, however, to regard solar influence as producing a cumulative effect in one of two ways, or by a combination of both For (1) time is necessarily an element in any influence acting upon the hard iron system of the earth—presuming the earth to possess such a system There are in fact indications in the results of § 82 that a system of this kind is perhaps connected with the American pole, yet even allowing the influence of time, it seems difficult to account for the peculiarities of the secular variation by an hypothesis of this nature But (2) any long continued variation of solar power would no doubt act cumulatively in producing an increase or diminution of the large ice fields round the poles of the earth In the course of time this cumulative change in the extent and disposition of these might perceptibly alter the distribution of the convection currents of the earth—and these, according to the views herein indicated, *might in their turn* perceptibly alter the earth's magnetic system

143 *Concluding Remarks* —If we agree to look for an explanation of terrestrial magnetism and its changes to strictly terrestrial processes, we may derive some assistance in our search from such considerations connected with symmetry as enable us, for example, at once to perceive that when two perfectly similar things are rubbed together we cannot have electrical separation, because there is no reason why the one should be positively and the other negatively electrified Suppose then that an observer stands at the equator and looks towards the north, and then turns his back upon the north and looks towards the south In the first position let him regard the northern system of meteorological processes and motions, and in the second the southern Now if symmetry obtained absolutely in these systems—that is to say, if the observer, whether he regarded the northern or the southern system of things, had in either case precisely similar phenomena at his right hand and at his left—then we should see no reason why the earth should be a magnet, or why one hemisphere should be the seat of magnetism of the one kind rather than of the other If then we regard meteorological processes and motions as being in some way the cause of terrestrial magnetism, we must direct our attention to that peculiar element which causes a want of perfect symmetry such as we have described in meteorological phenomena This element can hardly be anything else than the rotation of the earth, which is from left to right to an observer facing the north, but from right to left to an observer facing the south

144 Now if we look upon the terrestrial meteorological system modified by the earth s rotation as having produced somehow in the past the magnetic state of the earth, it seems most natural to regard the system which formerly produced this magnetic state as being likewise that which at present maintains it in its efficiency, and which also accounts for the various magnetic changes which take place It would seem therefore that terrestrial meteorology and terrestrial magnetism are probably cognate subjects, and that they ought to be studied together in the well founded hope that the phenomena of the one will help us to explain those of the other

Furthermore, if these meteorological processes—deriving their one sided character from the earth s rotation—are to be regarded as accounting not only for the origin but for the maintenance of the earth s magnetic system, we can hardly fail to imagine that these processes must derive part of the energy which they exhibit from that of the earth s rotation Tidal energy we know is derived from this source but we must likewise regard part of the energy displayed in convection currents whether in the air or in the ocean as derived no doubt from the same source And we may perhaps allow that in the phenomena of tidal action, as well as in those of convection currents of the air and ocean, there may be, not merely a transmutation of actual energy directly through friction into heat, but likewise a transmutation of it, ultimately perhaps into heat, but first through the intermediate agency of electrical currents which serve to maintain the magnetic state of the earth and to produce magnetic changes

Now if this be the case, if there be a large and complicated system of tidal and convection currents all tending to change the rotative energy of the earth ultimately into heat, whether directly through friction or indirectly through the medium of electricity, it is surely impossible with the present state of our knowledge to calculate with the smallest pretensions to accuracy at what rate this transmutation is taking place, and hence at what rate the velocity of the earth's rotation is being slowly diminished. (B S)

METHODISM

I. Wesleyan Methodism

The history of Wesleyan Methodism embraces—(1) the Methodism of Oxford, which was strictly Anglican and rigidly rubrical, though it was also more than rubrical, (2) the evangelical Methodism of the Wesleys after their conversion (in 1738), of which the Wesleyan doctrines of conversion and sanctification were the manifesto and inspiration, while preaching and the class meeting were the great motive and organizing forces,—a movement which before Wesley's death had developed into a form containing, at least in embryo, all the elements of a distinct church organization, although in its general designation and deliberate claims it purported to be only an unattached spiritual society, and (3) Wesleyan Methodism since the death of Wesley, which, by steps at first rapid and afterwards, though leisurely, distinct and consecutive, assumed an independent position, and has grown into complete development as a church.

1. *Oxford Methodism.*—This began in November 1729, when John Wesley, returning to Oxford from Lincolnshire, where he had been serving his father as curate, found that his brother Charles, then at Christ Church, had induced a few other students to join him in observing weekly communion. John Wesley's accession lent weight and character to the infant association. Their first bond of association, besides the weekly communion, was the common study of the Greek Testament, with which they joined regular fasting, the observance of stated hours for private devotion, the visitation of the sick, of the poor, and of prisoners, and the instruction of neglected children. They never themselves adopted any common designation, but of the variety of derisive names they received from outsiders that of "Methodists" prevailed,—a sobriquet the fitness of which, indeed, as descriptive of one unchanging and inseparable feature of Wesley's character (which he impressed also on his followers), was undeniable.

This first Oxford Methodism was very churchly. Between 1733 and 1735, however, a new phase was developed. Its adherents became increasingly patristic in their sympathies and tendencies, and Wesley came much under the influence of William Law. In regard to this period of his history, Wesley himself says that he

> "Bent the bow too far by making antiquity a coordinate rather than a subordinate rule with Scripture, by admitting several doubtful writings, by extending antiquity too far, by believing more practices to have been universal in the ancient church than ever were so, by not considering that the decrees of a provincial synod could bind only that province, and the decrees of a general synod only those provinces whose representatives met therein, that most of those decrees were adapted to particular times and occasions, and consequently, when those occasions ceased, must cease to bind even those provinces."

It was in 1736, during his residence in Georgia, whither he had gone as a missionary of the Propagation Society, that he learnt those lessons. Notwithstanding his ascetic severity and his rubrical punctilios, the foundations of his High Churchmanship were gradually giving way. When he returned to England he had already accepted the doctrine of "salvation by faith," although he had not as yet learned that view of the nature of faith which he was afterwards to teach for half a century. He had, however, as in the journal of his homeward voyage he tells us, learned, "in the ends of the earth," that he "who went to America to convert others was never himself converted to God." In this result his Oxford Methodism came to an end.

The original Methodism of Oxford never at any one time seems to have numbered as many as thirty adherents. There was a set called "Methodists," but there was no organization, no common bond of special doctrine or of discipline, there were habits and usages mutually agreed upon, but there was no official authority, only personal influence. The general features of the fraternity, if fraternity it may be called, seem to suggest closer analogies with the "Tractarian" school in its earlier stages than with anything else in modern history, and the personal ascendency of John Wesley may remind us in some measure of the influence exercised a century later by J. H. Newman. There was no more any germ of permanent organization in the Oxford Methodism of 1735 than in the patristic and "Tractarian" school of Oxford of 1833.[1]

2. *Methodism after Wesley's Conversion.*—John Wesley landed at Deal, on his return from Georgia, on February 1, 1738. His journals on the homeward voyage, says Miss Wedgwood,[2] "chronicle for us that deep dissatisfaction which is felt whenever an earnest nature wakes up to the incompleteness of a traditional religion, and his after life, compared with his two years in Georgia, makes it evident that he passed at this time into a new spiritual region." "By Peter Bohler,[3] in the hands of the great God," he writes in his journal, "I was, on March 5, fully convinced of the want of that faith whereby we are saved." This "conviction" was followed on March 24 of the same year (1738) by his "conversion."

Like most good men of that age in England, Wesley, before he came under the influence of his Moravian teacher, had regarded faith as a union of intellectual belief and of voluntary self submission—the belief of the creeds and submission to the laws of Christ and to the rules and services of the church, acted out day by day and hour by hour, in all the prescribed means and services of the church and in the general duties of life. From this conception of faith the element of the supernatural was wanting, and equally that of personal trust for salvation on the atonement of Christ. The work of Bohler was to convince Wesley that such faith as this, even though there might be more or less of divine influence unconsciously mingling with its attainment and exercise, was essentially nothing else than an intellectual and moral act or habit, a natural operation and result altogether different from the true spiritual faith of a Christian. This conviction led him a few days afterwards to stand up at the house of the Rev. Mr Hutton, College Street, Westminster, and declare that five days before he had not been a Christian. When warned not thus to despise the benefits of sacramental grace, he rejoined, "When we renounce everything but faith and get into Christ, then and not till then, have we reason to believe that we are Christians." It is true that for several years after this he remained High Church in some of his principles and opinions, but nevertheless his ritualism was dead at its roots.

---

[1] One evidence of this is to be found in the early and wide divergence of the various members of the Oxford Methodist company after their brief association at the university came to an end. We know which way the Wesleys went, we know also the separate path that their friend Whitefield made for himself. John Clayton, the Jacobite churchman, settled at Manchester, renounced the Wesleys after they began their evangelical movement, and remained an unbending High Churchman to the end. Benjamin Ingham became a great evangelist in Yorkshire, founded societies, and with his societies or churches, took the decisive step of leaving the Church of England and embracing the position of avowed Dissent. The saintly Gambold, a poet as well as a theologian and preacher, became a Moravian bishop. James Hervey was in after life a famous evangelical clergyman holding "Low" and Calvinistic views. These were the chief of the Methodists of Oxford.

[2] *John Wesley and the Evangelical Reaction of the 18th Century.*

[3] A disciple of Zinzendorf, then in England on his way to America.

This experience also made Wesley an evangelist. He had a forgotten gospel to preach,—the gospel by which men were to be converted, as he had been, and to be made “new creatures.” And this result, this new birth, was not dependent on any churchly form or ordinance, on any priestly prerogative or service, or on any sacramental grace or influence. To raise up, accordingly, by his preaching and personal influence, a body of converted men, who should themselves become witnesses of the same truth by which he had been saved, was henceforth to be Wesley's life work. This was the inspiration under which he became a great preacher; this also made him an organizer of his living witnesses into classes and societies. In the pulpit was the preaching power; in the class room was the private and personal influence. The vital link between the pulpit and the class meeting was the doctrine and experience of “conversion.” Thus Wesleyan Methodism is derived, not from Wesley the ritualist, but from Wesley the evangelist.

Wesley's doctrines offended the clergy. His popularity as a preacher alarmed them. The churches were soon shut against him. He attended the religious meetings—on a Church of England basis—which had existed in London and elsewhere for fifty years, so far as these were still open to him, the Moravian meetings, and meetings in the rooms of private friends, but these were quite insufficient for the zeal and energy of himself and his brother, who had been “converted” a few days before himself. Accordingly, in 1739, he followed the example set by Whitefield, and preached in the open air to immense crowds. In the same year also he yielded to the urgency of his followers and to the pressure of circumstances, and, becoming possessed of an old building called “the Foundery,” in Moorfields, transformed it into a meeting house. Here large congregations came together to hear the brothers. About the same time, in Bristol and the neighbouring colliery district of Kingswood, he found himself obliged, not a little against his will, to become the owner of premises for the purpose of public preaching and religious meetings. Here was the beginning of that vast growth of preaching houses and meeting rooms, all of them for nearly fifty years settled on Wesley himself, which, never having in any way belonged to the Church of England, became, through Wesley, the possession of the Methodist Connexion.

The religious societies through which the Wesleys, after their conversion, exercised at first their spiritual influence were in part, as has been intimated, Moravian,—that in Fetter Lane, of which the rules were drawn up by Wesley himself in 1738 (May 1), being the chief of these,—and in part societies in connexion with the Church of England, the successors of those which sprang up in the last years of the Stuarts, as if to compensate for the decay of Puritanism within the church. In 1739, however, a strong leaven of antinomian quietism gained entrance among the Moravians of England (Bohler himself having left for America in the spring of 1738), and Wesley, after vainly contending for a time against this corruption, found it necessary formally to separate from them, and to establish a society of his own, for which a place of meeting was already provided at the Foundery. This was the first society under the direct control of Wesley, and herein was the actual and vital beginning of the Wesleyan Methodist Society, that is, of Wesleyan Methodism. Hence the Wesleyans celebrated their centenary in 1839. It was not, however, till 1743 that Wesley published the Rules of his Society. By that time not a few other local societies had been added to that at the Foundry, the three chief centres being London, Bristol, and Newcastle. Hence Wesley called his Society, when he published the “Rules” in 1743, the “United Societies.” His brother's name was joined with his own at the foot of these Rules, in their second edition, dated May 1, 1743, and so remained in all later editions while Charles Wesley lived. Those Rules are still the rules of Wesleyan Methodism. Since Wesley's death they have not been altered. During his life only one change was made of any importance. In 1743 the offerings given weekly in the classes were for the poor, there being at that time no Conference and no itinerant preachers except the two brothers; after a few years the rules prescribed that the weekly contributions were to go “towards the support of the gospel.” The Society is described as “a company of men having the form, and seeking the power, of godliness, united in order to pray together, to receive the word of exhortation, and to watch over one another in love, that they may help each other to work out their salvation.” “The only condition previously required of those who desire admission into these societies” is “a desire to flee from the wrath to come, and to be saved from their sins.” The customary contribution was a minimum of a penny a week or a shilling a quarter.

In 1739 these societies were not divided into “classes.” But in 1742 this further step in organization was taken, and the change is recognized in the rules of 1743. Leaders were appointed to these classes, and became an order of spiritual helpers and subpastors, not ordained like lay elders in the Presbyterian churches, but, like them, filling up the interval between the pastors that “labour in the word and doctrine” and the members generally, and furnishing the main elements of a council which, in after years, grew up to be the disciplinary authority in every “society.” In every society there was from the beginning a “steward” to take and give account of moneys received and expended. After a few years there were two distinct stewards, one being specially appointed to take care of the poor and the “poor's money,” the other being, in general, the “society steward.” And, finally,—though hardly, perhaps, during Wesley's lifetime,—in the larger societies there came to be two stewards of each description. The leaders and stewards together constituted “the leaders' meeting,” of which, however, the complete circle of functions grew into use and into recognition only by degrees. The Rules of the Society, which are strict and searching, relate to worship, to conduct, and to the religious life, but do not once mention or refer to the Church of England, the parish church, or the parish clergy. The only authority at first was the personal authority of the two brothers, exercised either directly or by their official delegates. After years had passed away the leaders' meeting came to have an important jurisdiction and authority, but its rights and powers were neither defined nor recognized until after Wesley's death. From first to last there is no trace or colour of any Anglican character in the organization. Moravians or Dissenters might have entered the fellowship, and before long many did enter it who had either been Dissenters or, at any rate, had seldom or never entered a church. What would to-day be called the “unsectarian” character of his society was, indeed, in Wesley's view, one of its chief glories. All the time, however, this “unsectarian” society was only another “sect” in process of formation. Wesley for many years before his death had seen that, unless the rulers of the church should come to adopt in regard to his society a policy of liberal recognition, this might be the outcome of his life work. And it would seem as if in his private confidences with himself he had come in the end at times to acquiesce in this result.

Still more decisive, however, was the third step in the development of Wesley's "Society." The clergy not only excluded the Wesleys from their pulpits, but often repelled them and their converts from the Lord's Supper. This was first done on a large scale, and with a systematic harshness and persistency, at Bristol in 1740. Under these circumstances the brothers took the decisive step of administering the sacrament to their societies themselves, in their own meeting rooms, both at Bristol and at Kingswood. This practice having thus been established at Bristol, it was not likely that the original society at the Foundery would rest content without the like privilege, especially as some of the clergy in London acted in the same manner as those at Bristol. There were therefore at the Foundery also separate administrations. Here then, in 1740, were two—if we include Kingswood, three—separate local churches, formed, it is true, and both served and governed by ordained clergymen of the Church of England, but not belonging to that church or in any respect within its government. As thereafter during Wesley's life one of the brothers, or some cooperative or friendly clergyman, was almost always present in London and in Bristol for the administration of the sacraments, these communions, when once begun, were afterwards steadily maintained, the Lord's Supper being, as a rule, administered weekly. Both on Sundays and on week days full provision was made for all the spiritual wants of these "societies," apart altogether from the services of the Church of England. The only link by which the societies were connected with that church—and this was a link of sentiment, not an organic one—was that the ministers who served them were numbered among its "priests."

In 1741 Wesley entered upon his course of calling out lay preachers, who itinerated under his directions. To the societies founded and sustained with the aid of these preachers, who were entirely and absolutely under Wesley's personal control, the two brothers, in their extensive journeys, administered the sacraments as they were able. The helpers only ranked as laymen, many of them, indeed, being men of humble attainments and of unpolished ways. For the ordinary reception of the sacraments the societies in general were dependent on the parish clergy, who, however, not seldom repelled them from the Lord's table. So also for the ordinary opportunities of public worship they often had no resource but the parish church. The simple service in their preaching room was, as Wesley himself insisted, defective, as a service of public worship, in some important particulars; besides which, the visits of the itinerants were usually, at least at first, few and far between. Wesley accordingly was urgent in his advices and injunctions that his societies generally should keep to their parish churches; but long before his death, especially as the itinerant preachers improved in quality and increased in number, there was a growing desire among the societies to have their own full Sunday services, and to have the sacraments administered by their own preachers. The development of these preachers into ministers, and of the societies into fully organized churches, was, if not the inevitable, at any rate the natural, result of the steps which Wesley took in order to carry on the work that was continually opening up before him.

In 1744 Wesley held his first Conference. The early Conferences were chiefly useful for the settlement of points of doctrine and discipline and for the examination and accrediting of fellow labourers. They met yearly. Conferences were a necessity for Wesley, and became increasingly so as his work continued to grow upon him. It was inevitable also that the powers of the Conference, although for many years the Conference itself only existed as it were on sufferance, and only exercised any authority by the permission of its creator and head, should continually increase. The result was that in 1784 Wesley could no longer delay the legal constitution of the Conference, and that he was compelled, if he would provide for the perpetuation of his work, to take measures property of the Connexion. The legal Conference was defined as consisting of one hundred itinerant preachers named by Wesley, and power was given to the "legal hundred" continually from the first to fill up the vacancies in their own number, to admit and expel preachers, and to station them from year to year, no preacher being allowed to remain more than three years in one station.

By this measure Wesley's work was consolidated into a distinct religious organization, having a legally corporate character and large property rights. And yet Wesley would not allow this great organization to be styled a "church." It was only a "society"—the "United Society"—the Society of "the people called Methodists"—the "Methodist Society." And of its members all who were not professed Dissenters were by him reckoned as belonging to the Church of England, although a large and increasing proportion of them seldom or never attended the services of that church. The explanation of this apparent inconsistency is that Wesley admitted none to be Dissenters except such as were so in the eye of the law—those who, "for conscience sake, refused to join in the services of the church or partake of the sacraments administered therein"—and that he interpreted "the Church of England" to mean, as he wrote to his brother Charles, "all the believers in England, except Papists and Dissenters, who have the word of God and the sacraments administered among them."

But Wesley was to carry his Society to a yet higher pitch of development, and one which made it still more difficult to distinguish its character from that of a distinct and separate church. In 1738 Wesley had been theoretically a High Churchman. For some time even after he had entered upon his course of irregular and independent evangelism he continued to hold, in the abstract, High Church views. But in 1746 he abandoned once for all his ecclesiastical High Churchmanship, although he never became either a political or a latitudinarian Low Churchman after the standard and manner of the 18th century. He relates in his journal under date January 20, 1746 how his views were revolutionized by reading Lord (Chancellor) King's account of the primitive church. From this time forward he consistently maintained that the "uninterrupted succession" was a fable which no man ever did or could prove. One of the things taught him by Lord King's book was that the office of bishop was originally one and the same with that of presbyter; and the practical inference which Wesley drew was that he himself was a "Scriptural Episcopos," and that he had as much right as any primitive or missionary bishop to ordain ministers, as his representatives and helpers, who should administer the sacraments, instead of himself, to the societies which had placed themselves under his spiritual charge. This right, as he conceived it to be, he held in abeyance for nearly forty years, but at length he was constrained to exercise it, and, by so doing, in effect led the way towards making his Society a distinct and independent church.

In 1784, the American colonies having won their independence, it became necessary to organize a separate Methodism for America, where Methodist societies had existed for many years. Wesley gave formal ordination and letters of ordination to Dr Coke, already a presbyter of the Church of England, as superintendent (or bishop) for America, where Coke ordained Francis Asbury as presbyter and superintendent (or bishop), and Coke and Asbury together ordained the American preachers as presbyters. From that ordination dates the ecclesiastical commencement of American Episcopal Methodism—in which the bishops are only chief among the presbyters whom they superintend, superior in office but of the same order. The Episcopal Methodism of America represents today the largest aggregate of Protestant communicants and worshippers of the same ecclesiastical name to be found in any one nation in the world.

The following year (1785) Wesley ordained ministers for Scotland. There his societies were quite outside of the established Presbyterianism of the day, with its lukewarm "moderatism," while the fervid sects which had seceded from the state church would hold no terms with Arminians like Wesley and his followers. Hence Wesley was compelled to make special provision for the administration of the sacraments in Scotland. He therefore ordained some of his ablest and most dignified preachers, was careful to give them formally in his correspondence the style and title of "Reverend," and appointed them to administer the sacraments north of the Tweed.

At length, in 1788, Wesley ordained a number of preachers (Mr Tyerman says seven) to assist him in administering the sacraments to the societies in England, and of these he ordained one (Alexander Mather) to be superintendent (or bishop), his brother Charles being now dead, and Dr Coke sometimes absent for long periods in America. The number of societies which demanded to have the sacraments administered to them in their own places of worship continually increased, and their claims were often too strong to be resisted, especially when the parish priest was either a public opponent of the Methodists or a man of disreputable conduct Before Wesley's death (in 1791) it would seem that there were more than a dozen of his preachers who had at different times, in Scotland or in England, been ordained to administer the sacraments

The foregoing view of the development of Methodism as an organization during the lifetime of its founder, will have conveyed a general idea of its structure and polity There is one cardinal, though variable, element in its organization, however, of which there has as yet been no occasion to speak The societies of Methodism—each of these consisting of one or more "classes"—were themselves grouped into circuits each of which was under the care of one or more of Wesley's Conference preachers, who were called his 'assistants' or "helpers,' the assistant being the chief preacher of a circuit, and the helper being a colleague and subordinate The "assistants were directly responsible to Wesley, who had absolute power over them, and exercised it between the Conferences The same power he equally possessed in the Conference, at the yearly meetings but he made it a rule, during his later life to take counsel with the Conference as to all matters of importance affecting the permanent status of the preachers personally, or relating to the societies and their government He thus prepared the Connexion, both preachers and people to accept the government and the legislative control of the Conference after his death

At the time of Wesley's death there were in Great Britain, the Isle of Man and the Channel Islands, 19 circuits, 227 preachers and 57,562 members In Ireland there were 29 circuits, 67 preachers, and 14 006 members There were also 11 mission circuits in the West Indies and British America, 19 preachers and 5300 members The number of members in the United States was returned as 43,265.

It has already been explained that in connexion with each society there was a leaders meeting, of which society stewards and poor stewards as well as leaders were members It must here be added that each circuit had its quarterly meeting of which at first, only the society stewards and the general steward (or treasurer) for the circuit, in conjunction with the itinerant preachers were necessary members Leaders however in some circuits were very early, if not from the first associated with the stewards in the quarterly meeting, or at least had liberty to attend The quarterly meeting was not defined in Wesleyan Methodism until the year 1852 The leaders meeting had no defined authority until some years after Wesley's death Discipline including the admission and expulsion of members lay absolutely with the 'assistant subject only to appeal to Mr Wesley Many years however, before Wesley's death it had become the usage for the assistant' or, in his absence the "helper his colleague, to consult the leaders meeting as to important questions either of appointment to office or of discipline As the consolidated society' approached towards the character of a "church, the leaders meeting began to acquire the character and functions of a church court, and private members to be treated in regard to matters of discipline, as having a status and rights which might be pleaded before such a 'court ' The rights, indeed, which soon after Wesley's death were guaranteed to leaders meetings and members of society had, there can be no doubt so far grown up before his death, as to be generally recognized as undeniable

' Bands were a marked feature in early Methodism but in later years were allowed at least in their original form to fall out of use There is no reference to them in the ' Minutes of Conference after 1768 although till after Wesley's death they held a place in the oldest and largest societies Originally there were usually in each considerable society four bands the members of which were collected from the various society classes—one band composed of married and another of unmarried men, one of married and another of unmarried women All the members of society however, were not of necessity members of bands Some maturity of experience was expected, and it was the responsibility of the assistant to admit into band or to exclude from band After Mr Wesley's death where "bands so called were kept up, they lost their private character and became weekly fellowship meetings for the society

The "love feast was a meeting the idea of which was borrowed from the Moravians but which was also regarded as reviving the primitive institute of the *agape* In the love feast the members of different societies come together for a collective fellowship meeting One feature of the meeting—a memory of the primitive *agape*—is that all present eat a small portion of bread or cake and drink of water in common

It may be supposed that in such a system as Methodism a large number of preachers and exhorters from all the social grades included within the societies could not but be continually raised up These, during Wesley's life, acted entirely under the directions of the assistant, and were by him admitted or excluded subject to an appeal to Wesley Once a quarter—often in conjunction with the circuit quarterly meeting—a meeting of these local lay helpers, called "local preachers," was held for mutual consultation and arrangement, and to examine and accredit candidates for the office

3 *Wesleyan Methodism after Wesley's Death* **(1791).**—When Wesley died the Conference remained as the bond of union and fountain of authority for the Connexion. But between the meetings of Conference Wesley had acted as patriarch and visitor with summary and supreme jurisdiction The first need to be supplied after his death was an authority for the discharge of this particular function In America Wesley had organized a system of bishops (presbyter bishops), presbyters or elders, and deacons or ministers on probation Among some of those preachers who had been most intimate with Wesley there was a conviction that his own judgment would have approved such a plan for England No document, however, remains to show that such was his desire The only request he left behind him for the Conference to respect was one which rather looked in another direction—the well known letter produced before the Conference on its first meeting after his death by his friend and personal attendant, Mr Bradford, in which he begged the members of the legal hundred to assume no advantage over the other preachers in any respect The preachers, accordingly, in their first Conference after Wesley's death, instead of appointing bishops, each with his diocese or province, divided the country into districts, and appointed district committees to have all power of discipline and direction within the districts, subject only to an appeal to the Conference, all the preachers exercising equal rights also in the Conference, the "legal hundred" merely confirming and validating *pro forma* the resolutions and decisions of the whole assembly

At first the preachers stationed in the districts were instructed to elect their own chairmen, one for each district. But the plan was speedily changed, and the chairmen were elected each year by the whole Conference, and this method has been maintained ever since The "district meetings"—as they are generally called—are still "committees ' of the Conference, and have *ad interim* its power and responsibilities as to discipline and administration Originally they were composed exclusively of preachers, but before many years had passed circuit stewards and district lay officers came to be associated with the preachers during the transaction of all the business except such as was regarded as properly pastoral

The relation of the Conference to the government of the Connexion having thus been determined, the question which next arose, and which occupied and indeed convulsed the Connexion for several years (1792–95), was that of the administration of the sacraments, especially of the Lord's Supper, to the societies The societies generally insisted on their right to have the sacraments from their own preachers Many of the wealthier members, however, and in particular a large number of the trustees of chapels, opposed these demands At length, between 1794 and 1795, after more than one attempt at compromise had been made by the Conference, the feeling of the societies as against the trustees became too strong to be longer resisted, and accordingly at the Conference of 1795 the "plan of pacification" was adopted, the leading provision being that, wherever the majority of the trustees of any chapel, on the one hand, and the majority of the stewards and leaders, on the other, consented to the administration of the sacraments, they should be administered, but not in opposition to either the one or the other of these authorities. In England the Lord's Supper was always to be administered after the Episcopal form, in Scotland it might still, if necessary, be administered, as it had commonly been before, after the Presbyterian form In any case, however, "full liberty was to be left to give out hymns and to use exhortation and extemporary prayer " The result was that within a generation the administration of the sacraments to the societies came to be the universal rule By this legislation the preachers assumed the powers of pastors, in accordance, however, only and always with the desire and choice of their flocks No formal service or act of ordination was brought into use till forty years afterwards All preachers on probation for the ministry, after the completion of their probation, were "received into full connexion" with the Conference, this reception implying investment with all pastoral prerogatives Modern Methodism has developed more fully and conspicuously the pastoral idea

No sooner was the sacramental controversy settled than the further question as to the position and rights of the laity came to the front in great force A comparatively small party, led by Alexander Kilham, imported into the discussion ideas of a republican complexion, and demanded that the members in their individual capacity should be recognized as the direct basis of all power, that they should freely elect the leaders and stewards, that all distinction in Conference between ministers and laymen should be done away (elected laymen being sent as delegates from the circuits in equal number with the ministers), that the ministry should possess no official authority or pastoral prerogative, but should merely carry into effect the decisions of majorities in the different meetings In the course of a very violent controversy which ensued, pamphlets and broadsheets, chiefly anonymous, from Kilham's pen, advocating his views and containing gross imputations on the ministers generally, and in particular on some not named but distinctly indicated, were disseminated through the societies The writer was tried at the Conference of 1796, condemned for the publication of injurious and unjustifiable charges against his brethren, and by a unanimous vote expelled from the Conference In the following year he founded the "New Connexion," the earliest of the organized secessions from Wesleyan Methodism

Views much more moderate than Kilham's prevailed in the Connexion at large At the Leeds Conference of 1797 the basis was laid of that system of balance between the prerogatives of the ministers and the rights of the laity which has been maintained in its principles ever since, and which, in reality, has governed the recent provisions (1877-78) for the admission of lay representatives into the Conference not less than the former developments of Wesleyan Methodism The admission of members into the society had, up to 1797, been entirely in the hands of the itinerant preachers,—that is, the "assistant," henceforth to be styled the "superintendent," and his "helpers" The new regulations, without interfering with the power of the ministers to admit members on trial, declared that "the leaders' meeting shall have a right to declare any person on trial improper to be received into society, and after such declaration the superintendent shall not admit such person into society", also that "no person shall be expelled from the society for immorality till such immorality be proved at a leaders' meeting"[1] For the appointment of church officers (leaders and stewards) the following regulations were made, the second based on recognized usage, the first on general but not invariable practice —

"1 No person shall be appointed a leader or steward or be removed from his office, but in conjunction with the leaders' meeting, the nomination to be in the superintendent, and the approbation or disapprobation in the leaders' meeting

"2 The former rule concerning local preachers is confirmed,—viz, that no man shall receive a plan as a local preacher, without the approbation of a local preachers' meeting

The Conference at the same time made several provisions for carrying out the process, which had been going on for some years, of denuding itself of direct responsibility in regard to the disbursement of the Connexional funds The principle was established that such matters were to be administered by the district committees acting in correspondence with the quarterly meetings of the circuits It was also provided that circuits were not to be divided without the consent of the respective quarterly meetings, and, finally, it was resolved that, in the case of any new rule made by the Conference for the Connexion, its action within a circuit might be suspended for a year by the quarterly meeting, if it disapproved of the rule If, however, the Conference, after twelve months interval, still adhered to the new rule, it was to be binding on the whole Connexion

The powers of district committees, as defined by former Conferences, were in 1797 confirmed and enhanced, special powers being given to special meetings of these committees convened when necessary to settle the affairs of a distracted circuit In the same Conference all the principal rules of Methodism, in regard both to the ministers and the laity, were collected and (in a sense) codified, including the new regulations adopted that same year, and the whole, under the title "Large Minutes, was accepted as binding by the Conference, each minister being required to sign his acceptance individually This compendium, itself based on one which had been prepared by Wesley, is still accepted by every Wesleyan minister on his ordination as containing the rules and principles to which he subscribes During the sitting of this critical Conference at Leeds an assembly of delegates from bodies of trustees throughout the kingdom was simultaneously held The form of the regulations enacted by the Conference was, to a considerable extent, determined by the nature and form of the requests made by this body of trustees There was one request, however, which the Conference distinctly declined to grant—namely, that for lay delegation to the Conference The Conference replied that they could not admit any but regular travelling preachers into their body, and preserve the system of Methodism entire, particularly the "itinerant plan" It was not until many years afterwards that anything was heard again as to this matter

By the settlement now described the outlines of Methodism as an organized church were fairly completed Many details have since been filled in, and many changes have been made in secondary arrangements, but the principles of development have remained unchanged The Connexion after 1797 had a long unbroken period of peaceful progress The effect of the 'Kilhamite' separation, indeed, was after 1797 not greatly felt by the parent body The number of Methodists in the United Kingdom in 1796, the year of Kilham's expulsion, was 95,226, in 1797 it was 99,519, in 1798 the New Connexion held its first Conference, and reported 5037 members, the number of the parent body being 101,682 Nor was it till 1806 that the New Connexion reached 6000

During the period of quiet growth and development which followed 1797 the influence of one superior mind (Dr Jabez Bunting, 1779-1858) was to prevail with increasing sway This was to be the period of the gradual development of lay co operation in the administration of the various departments of Connexional extension and enterprise—a development which prepared the way for the important legislation of 1852 and following years and for the ultimate settlement of the respective provinces and powers of the ministers and laity which was made in 1877–78 It was also to be the period of the gradual completion of the pastoral idea, in its practical application to the ministers of the body This period may be defined as extending from the revolutionary epoch of 1791 97 to the epoch of political and municipal reform agitation, 1828 35 which coincides with a second period of politico-ecclesiastical agitation in Wesleyan Methodism

---

[1] In this regulation it was assumed that the old rule of society by which a member disqualifies and virtually expels himself by continued absence from class, without reason for such absence still held good The case provides only for expulsions for 'immorality Subsequent legislation has introduced a provision which ensures to any member before he ceases to be recognized on account of non attendance the right of having his case brought before a leaders meeting if he desires it This rule of 1797 has always been understood by the Conference as constituting the leaders meeting in effect a jury, leaving the superintendent with his colleague or colleagues as advisers to act as judge Appeal has always lain from the leaders meeting to the district meeting, and, finally, to the Conference.

In 1797 the Conference, as already mentioned, had refused to allow elected laymen—or lay delegates—any place either in the Conference or in district committees Within a few years after 1800 however the practice grew up for the circuit stewards to attend the district committees during the transaction of financial business and in 1815 this usage was recognized in the Minutes of Conference as an established rule, and it was enacted that no general increase of the income of the ministers should be sanctioned by the Conference until approved by a majority of the district committees during the attendance of the circuit stewards Since the adoption of this rule the lay element in the district committees has steadily increased and developed Another characteristic and important feature in the organization of Wesleyan Methodism, which grew into distinct form and prominence during the period now under review, was that of the administration of all the Connexional departments, except such as were regarded as properly pastoral by means of mixed departmental committees, appointed at each successive Conference These committees made recommendations to the Conference in regard to such new legislation as they thought desirable and to the appointment of the members of committee and, for each department, a large committee of review, of which the members of the ordinary committee of management formed the nucleus came to be held each year immediately before the Conference In these committees the numbers of ministers and of laymen were equal On this principle, between 1811 and 1835, provision had been made for the management of all the funds of the Connexion and their corresponding departments of administration The first mixed committee appointed by the Conference was the committee of privileges in 1803

The development of the pastoral position and character of the ministers of the body after 1797 could not but advance on a line parallel to the development of the position and claims of the laity In 1818 the usage of the Conference was conformed to what had long been the ordinary unofficial custom and the preachers began to be styled in the *Wesleyan Methodist Magazine* and in other official publications "Reverend, a fact which may seem trivial, but which in reality was of important significance

In 1834, after the idea had been long entertained and the project had been repeatedly discussed, it was determined to establish a theological institution for the training of ministerial candidates There are now four colleges, with two hundred and fifty students In 1836 the practice of ordination by imposition of hands was adopted

Such advances, however, as these in the general organization and development of the Connexion and especially in the status and professional training of the ministers, could not be made in such a body without offence being given to some, whose tendencies were to disallow any official distinction between the ministry and the laity, and who also objected to the use of the organ This levelling element was strong in the West Riding of Yorkshire, and in 1828, on the placing of an organ in Brunswick Chapel, Leeds, by the trustees, with the consent of the Conference, a violent agitation broke out The consequence was a disruption, the first since 1798 under the title ' Protestant Methodists But this was absorbed, some years later in a more considerable secession

In fact, the Connexion was in 1828 entering on a period of agitation The current of political affairs was approaching the rapids of which the Reform Act marked the centre and the point of maximum movement A body like Wesleyan Methodism could not but feel in great force the sweep of this movement It is true that Wesleyan Methodism as such has never been political, that few of its numbers cultivated extreme politics, and that the ministers and the better classes of the "Society were strongly Conservative in their general tone Nevertheless the mass of the community shared in the general movement of the times and the Conservative tone of the ministers and of most of the well to do laity was not in full harmony with the sympathies of the people generally Accordingly the elements of disturbance, which only partially exploded in the "Protestant Methodist secession continued to make themselves felt, in different parts of the Connexion, during the following years of political controversy The decision of the Conference in 1834 to provide a college for the training of ministerial candidates gave special offence to the malcontents Such an occasion was all that was wanting for the various discontents of the Connexion to gather to a head The demands made by the agitators proceeded on a basis of democratic ecclesiasticism such as it is very difficult to apply successfully to a system of associated churches The result was a third secession, based on the same general ground of ecclesiastical principles as the two preceding, which was organized in 1836, and with which the "Protestant Methodists" eventually coalesced This new secession was known first as the "Wesleyan Methodist Association' , but for a number of years past it has been merged in a still larger body of seceders designated "The Methodist Free Churches " Its leader at the first was the Rev Dr Warren, who left it, however, not many months after it was formed, and took orders in the Church of England [1]

The controversies of 1835–36 left their mark on the legislation and official documents of the Connexion The principles of 1797 remained intact, some farther guards only being added to prevent any danger of hasty or irresponsible action on the part of superintendents, and at the same time "minor district meetings" being organized in order to facilitate appeals One error was, however, committed by the Conference In 1797 no provision had been made for bringing the circuit, through its quarterly meeting, into direct relations with the Conference In 1836 a right of direct memorial to the Conference was given to the circuit quarterly meeting , but it was so fenced round with conditions and limitations as to make it practically inoperative, and at the same time provocative of suspicion and irritation

The effect of the secession of 1836 on the general progress of the Connexion was not great The number of members reported in 1835 in Great Britain and Ireland was 371,251 (there being a decrease in England of 951), in 1836 381,369, in 1837 384,723 For the next ten years the advance of the Connexion in numbers and in general prosperity was apparently unprecedented The Centenary Fund of 1839–40 amounted to £221,000 In the midst, however, of all the outward prosperity of Methodism—partly perhaps in consequence of it—very perilous elements were at work The revolutionary ideas of the Chartist period (1840–48) and of Continental politics (1848–49) reacted on Wesleyan Methodism as the political ideas of 1791 and of 1831 had done at those epochs The embers of old controversies—ecclesiastical, quasi political, and personal—still smouldered, and at length burst into fresh flame From 1844 a strong spirit of opposition to the leaders of the Connexion, and especially to Dr Bunting, was fanned by the circulation of anonymous "fly leaves of a very scurrilous character At the same time the policy of the Conference and of the ministers in their circuits had proceeded more than was wise on the old lines The general administration relied too much on the footing of implicit confidence on the part of the people and on the power of official prerogative in the hands of the minister The memorial law of 1836 was indicative of the too exclusive spirit of pastoral government which had prevailed The wisdom of Dr Bunting had for five and twenty years led the way in gradually liberalizing both the polity and the policy of Methodism, and adapting them to the changing conditions of the times But this wisdom seems to have found its limits before 1849, when the internal dissensions reached their climax In that year James Everett, the chief author of the fly sheets, and two other ministers, Samuel Dunn and William Griffith who had identified themselves with him, were expelled A disastrous agitation followed No distinct secession took place till after the Conference of 1850 The union of the ' Methodist Free Churches, in which was incorporated the "Wesleyan Association (of 1836), was formed by the seceders The "New Connexion" also received some thousands of the seceders into its ranks But by far the greatest part of those who left went with neither of these bodies

Between 1850 and 1855 the Connexion in Great Britain and Ireland lost 100,000 members, and not till 1856 did it begin to recover In that year the numbers were returned as 282,787, showing a small increase over the preceding year Since then peace and unity have prevailed unbroken

The convulsion of 1849–52 taught the Connexion, and in particular the Conference, lessons of the highest importance In 1852 the quarterly meeting was so defined as to make it the great representative meeting of the circuit, including stewards, leaders, local preachers, and trustees The right of memorial to the Conference was given to it in the widest and freest sense These powerful bodies invite ministers to the circuits, or decline so to do, determine and pay their "allowances," as salaries to ministers are still called in the Connexion, and review all the interests of the circuits, spiritual or financial They had also conferred upon them in 1852 the right to appoint a circuit jury of appeal from the verdict and findings of a leaders' meeting in certain cases of discipline Since 1852 Conference legislation has still proceeded in the direction of recognizing and enlarging the functions and rights of the laity The committee of review system, already spoken of, had been considerably developed between 1835 and 1849, and included every department of ordinary administration In 1861, however, whilst a representation of the departmental executive committees formed still the leading element in each committee of review, a great improvement was made in their constitution by giving to each of the districts of British Methodism the right to send a lay representative to attend these preparatory Conference committees. In 1877 and 1878 the final and natural consummation of the whole course of advance since 1791 was effected in the constitution of the united Conference of ministers and lay representatives. The ministers meet by themselves to discharge the functions which belong to them as the common pastorate of the Connexion. As to all the points involved in their specific character and common responsibility, as the mutually exchanging and itinerating pastor in common of a vast common flock, they take mutual counsel in a separate assembly. The Conference, in its ministerial and lay or representative session, meets after the pastoral business is completed, and occupies a full week between Sundays in discussing and settling the business of all the funds and the general administrative departments of the body. The Conference in its pastoral session assembles on the last Tuesday in July, that session closing on the Friday or Saturday week following; the representative session occupies the following week. It is legally necessary that the decisions of the Conference in both its sessions should be confirmed and validated by the vote of the "legal hundred." This confirmation is, however, given as a matter of course.

---

[1] This ' Warrenite secession as at first it was commonly called gave rise to a lawsuit which led to the judicial recognition by the Court of Chancery of the Conference Deed Poll of 1784 and the Large Minutes of 1797 as documents having the force of public law in the administration of Wesleyan Methodism

The Conference in its pastoral session is not formally representative. To each district is assigned by the preceding Conference a certain amount of representation, there being at present thirty five districts. The numbers allocated to the districts vary according to circumstances. The total number of ministers and laymen composing the Conference in its representative session is 480, or 240 ministers and 240 laymen. The basis of the lay representation in the Conference is the constituency of lay officials in the district committees. The Connexion at large is represented by the lay officials of the general Connexional departments. The business transacted in the Conference during its representative session relates to all the Connexional departments of general administration, viz., the committee of privileges, foreign missions, the maintenance and education fund (and the schools) for ministers' children, chapel affairs (general, metropolitan, and provincial), the home mission and contingent fund, district sustentation funds, army and navy evangelization, lay mission work, the worn out ministers' and ministers' widows' fund, the theological institution with its four colleges, Sunday and day schools and the children's home and orphanage, higher education, the extension fund of Methodism, alterations and divisions of circuits and districts, and the Lord's Day observance and temperance questions.

The president of the Conference is chosen by the ministers by ballot on the opening of the pastoral session. After the election of president follows that of secretary. These elections, however, cannot take place until the vacancies in the hundred have been filled up. Such vacancies are caused by death, by absence for two years together without a dispensation, by expulsion, or by superannuation, which takes place ordinarily after two years' retirement from the full work of the ministry.

The principal statistics of the denomination at the last Conference (1882) were as follows:—

	Members	On Trial	Ministers	On Trial	Retired or Supernumerary Ministers	Sunday Scholars
Great Britain	393 754	40 653	1 549	81	279	829 666
Ireland	24 4[illegible]	7[illegible]6	200	18	43	
Foreign missions[1]	89 [illegible]69	12 934	348	198	16	

Of the Sunday scholars in Great Britain 177 965 were over fifteen years of age, and 93,127 were members of society or on trial as members.

Wesleyan Methodism in Ireland has always been part and parcel of British Methodism, but since 1782 it has had a branch Conference of its own. The acts of this Conference are in accordance with a provision in the Conference Deed Poll, made valid by the concurrence with them of a delegate from the British Conference, who is to the Irish Conference what the legal Conference is to the British Conference. Ten ministers of the Irish Conference are members of the "legal hundred" of the British Conference. The "plan of pacification" of 1795 was not carried out at the time by the Irish Conference. In the year 1816 however it was adopted in Ireland. The result was a secession which assumed the designation "Primitive Wesleyans," a very different body from the Primitive Methodists of England. In 1878 the Primitive Wesleyans were reunited to the parent Connexion. The number of members in Ireland has, owing to emigration, not increased of late years. The last return showed 24,475 members.

Affiliated Conferences.—For more than twenty years there were several "affiliated Conferences" of British Methodism. But there are now only two—the *French Methodist* Conference, and that of *South Africa*,—the latter constituted quite recently (1882). Since 1852 French Methodism has been under an affiliated Conference. The dimensions of the French Connexion, however, are very small, and it is dependent to a considerable extent on pecuniary aid furnished by the Wesleyan Missionary Society. The last statistical return showed 1769 members, 126 members on trial, 27 ministers, 1 minister on trial, and 3 supernumerary or retired ministers. The British Conference has a right of veto as to certain points of legislation in the case of affiliated Conferences.

Australasian Methodism was for more than twenty years under an affiliated Conference, dating from 1854. Since 1876 however, the Australasian Conference has been independent. The General Conference meets once in three years, having under it our annual Conferences—one for New South Wales and Queensland, another for Victoria and Tasmania, a third for South Australia, and a fourth for New Zealand. These Conferences—the general and the annual—are all mixed and representative after the same general pattern as the British Conference. They have also under their charge, and as part of their Connexion, the Wesleyan missions in Tonga and Fiji, which were begun by the parent body before the original affiliated yearly Conference for Australasia was organized. The numbers in 1881 were for the Methodism of Australia 28,310 members with 362 ministers, and for the South Sea missions 33 411 members with 16 missionaries of European blood and a very large number of native ministers and assistant ministers.

Canadian Methodism was also affiliated till 1873, when it became an independent Connexion. It includes six provincial annual Conferences and one General Conference which meets every three years. The General Conference is mixed and representative; the annual Conferences are purely ministerial. Canadian Methodism occupies a powerful position in the Dominion. It numbers as nearly as can be ascertained about 116 000 members, and is strongest in Upper Canada. It possesses a university—the Victoria University in Upper Canada.

The Doctrines of Methodism.—In doctrine all branches of Methodism are substantially identical. Wesley's doctrines are contained in fifty three sermons known as the "four volumes," and in his *Notes on the New Testament*. The Conference has, however, published two catechisms, one for younger the other for older children, of which a new and carefully revised edition has lately been completed.[2] In general, Wesleyan theology is to be described as a system of evangelical Arminianism. In particular, Wesleyan divines insist on the doctrines of original sin, general redemption, repentance, justification by faith, the witness of the Spirit, and Christian perfection,—or, as it has been customary for Methodists to say, the doctrines of a "present, free, and full salvation." By the witness of the Spirit is meant a consciousness of the Divine favour through the atonement of Jesus Christ. Wesleyans have often been represented as holding the Calvinistic doctrine of "assurance." The word, however, is not a Wesleyan phrase, and assurance, so far as it may be said to be taught by Methodists, signifies, not any certainty of final salvation, but merely a "sense of sin forgiven."[3]

II. AMERICAN EPISCOPAL METHODISM

The beginnings of American Methodism are traceable to the year 1766, when a few pious emigrants from Ireland introduced Methodism into New York. On receiving an appeal in 1768 from the New York Methodists, who were engaged in building a preaching house, Wesley laid the case of America before the Conference at Leeds in 1769, and two preachers, Boardman and Pilmoor, volunteered to go to the colonies. Boardman went to New York, Pilmoor to Philadelphia. In 1771 two other Methodist itinerants, Francis Asbury—the most famous name in American Methodism—and Richard Wright, went out to America. In 1773 Thomas Rankin, a preacher of experience sent out by Wesley, held the first Conference in Philadelphia, when there were 10 itinerant preachers and 1160 members After the breaking out of the War of Independence the English Methodist preachers were unpopular, and all but Francis Asbury went back to England At the end of the war, however, in 1784, Wesley sent out Dr Coke, and American Methodism was organized as an independent church, with Dr Coke and Francis Asbury as its presbyter bishops The history of American Methodism since that period is too vast and complicated for any attempt to be made to summarize it here Methodism is more properly national in its character as an American church than any church in the States In Massachusetts and some other of the New England States it is less powerful than Congregationalism, which still retains there much of its ancient predominance, in the city of New York it is less powerful than Presbyterianism, and, indeed, occupies a position less generally influential than might have been expected But

---

[1] Chiefly in the West Indies, Africa, India and China.

Besides Wesley's *Sermons* and *Notes*, his *Appeals* and his treatise on *Original Sin* in reply to Dr Taylor of Norwich should be read in order to appreciate his theological views. After these may be particularly noted Joseph Benson's *Commentary*, Watson's *Institutes* (3 vols.), Dr Pope's *Compendium of Theology*

For the history and constitution of Wesleyan Methodism the following works may be consulted:—Wesley's Works, especially his *Journals*; Southey's *Wesley*; Tyerman's *Wesley*; Rigg's *Living Wesley*, and *Churchmanship of John Wesley*; Jackson's *Life of Charles Wesley*; *Minutes of Conference*, vol. i. 1744–98; Dr George Smith, *History of Wesleyan Methodism*, 3 vols.; Dr Abel Stevens, *History of Methodism*, 3 vols.; Pierce, *Polity of Methodism*; Dr Williams, *Constitution and Polity of Wesleyan Methodism*; Rigg, *Connexional Economy*; and the *Minutes*, 1877 to 1881.

and in Cincinnati, it not strong in New Y

very strong in the State, and generally throughout the western and mid western States it is the prevalent form of faith and worship In the south, also, it is more powerful than any other church

American Methodism is Episcopal But its Episcopacy is neither prelatical nor diocesan The bishops are superintending presbyters and they visit the whole territory of Methodism in rotation, holding (presiding over) the annual Conferences These Conferences are purely ministerial But the General Conference which meets once in four years and which is the Conference of legislation and final appeal is mixed and representative The first General Conference was held in 1792 the first delegated or representative Conference in 1812 the first mixed or ministerial and lay General Conference in 1872 There were till lately no district assemblies in the Episcopal Methodism of America and now there are but few The bishops maintain the unity of the Connexion in the interval between the General Conferences by their visitation and by their conjoint council A sub episcopal class of ministers also called presiding elders supplement the action and superintendency of the bishops *These preside over districts holding all the circuit quarterly meetings* and holding the district meetings if any such meetings have been organized

American Episcopal Methodism is distributed into five distinct sections or churches which, however differ from each other in no points of any importance as respects organization or discipline still less doctrine The American Methodist Episcopal Church South became a separate organization in 1847 by reason of the slavery controversy The coloured churches of which there are three sprang up distinctly from local causes The following are the latest available statistics —

	Itinerant Ministers	Local Preachers	Lay Members
Methodist Episcopal Church	12 142	12 3[illegible]3	1 71[illegible] [illegible]7
South	4 004	8[illegible]8	83[illegible] 831
African	1 832	9 [illegible]60	391 [illegible]44
Methodist Episcopal Zion Church	1 650	3 [illegible]50	300 000
Coloured Methodist Episcopal Church	638	683	11[illegible] [illegible]00
		[illegible]4	3 [illegible] 442

In the Methodist Episcopal Church alone there are one hundred annual Conferences, visited by twelve bishops This church has more than twenty universities, of which some are distinguished schools of learning Boston University is one of the most recent and one of the chief The principal foreign missions are in India China, and Japan The Methodist Church South also has some influential universities particularly that at Nashville, and has missions, in particular in Japan and China

Besides these Methodist Episcopal churches, with their total of 3,358 000 church members there are two other churches which do not assume the name at all but are yet essentially Methodist in doctrine and discipline not varying in any important particulars from the Episcopal Methodism of America Of these one is called the United Brethren, with 1[illegible]7 000 members, the other the Evangelical Association with 113 000 members [1]

Non Episcopal American Methodism —The bodies included under this head are chiefly secessions from the original stock of American Methodism founded on principles of democratic church government, analogous to those of the English Methodist secessions The only considerable body, however, is the Methodist Protestant Church, with 125,000 members The minor bodies, four in number, count altogether less than 60,000 members, the principal being the American Wesleyan Church, with 25,000 members

III Other Methodist Bodies in Britain

The bodies still to be noticed, while differing as to points of church government, agree as to doctrine and in general as to the means of grace and as to inner spiritual fellowship with the parent "Connexion" They all maintain class meetings and love feasts, have leaders' meetings and quarterly meetings, and largely employ local preachers

The Methodist New Connexion was founded in 1797–98 by Alexander Kilham, who died in 1798 Its general principles are indicated above Its statistics for 1881 were as follows —183 ministers and 27,770 members (including those on mission stations, besides 3882 on trial), and 74 744 Sunday scholars [2]

United Methodist Free Churches —This organization in its original form must be identified with the Wesleyan Methodist Association of 1836 That body first absorbed into itself, in great part, the "Protestant Methodists of 1828 It was afterwards greatly increased and its organization in some points modified, when a large number of the seceders from the parent Connexion in 1850 52 joined its ranks The main body of its Conference does not consist, like that of the New Connexion of an equal number of circuit ministers and elected circuit lay delegates, but of circuit delegates, whether ministerial or lay, elected without any respect to office, ministerial or other Its circuits also are independent of the control of the Conference The Connexional bond accordingly, in this denomination is weak, and the itinerancy is not universal or uniform in its rules or its operation The amalgamation between the Wesleyan Methodist Association and the "Wesleyan Methodist Reformers" of 1850 took place in 1857 At that time the combined churches numbered 41,000 At present (1881 82) they number 72,839, including 7772 members on the mission stations, besides 7824 on trial The number of ministers is 392, with 40 retired or "supernumerary ministers The number of Sunday scholars is 190 957 [3]

Primitive Methodism —In this earnest and hard working denomination the ministers of whom some are women, are very literally ' the servants of all The Conference is composed, in addition to twelve permanent members, of four members appointed by the preceding Conference and *of delegates from district meetings* The principle of proportion is that there should be two laymen to one minister or 'travelling preacher, and the ' travelling preachers have no pastoral prerogative whatever The Conference is supreme, and the Connexional bond is strong This body was founded by Hugh Bourne and William Clowes local preachers who were separated from the Wesleyan Connexion, the former in 1808, the latter in 1810, because of their violation of Conference regulations as to camp meetings and other questions of order The Conference had, in 1807, pronounced its judgment against camp meetings, which had been introduced into the country from America, whereas Bourne and Clowes were determined to hold such meetings Founded thus by zealous and "irregular lay preachers, "Primitive Methodism, as the resulting new body called itself bears still in its organization, its spirit and its customs strong traces of its origin It has been a very successful body, aiming simply at doing evangelistic work, and is now numerous and powerful, numbering among its ministers, not only many useful preachers, but some of marked originality and power and also of superior cultivation There has for many years past if not from the beginning, been a very friendly feeling between the old Wesleyan Connexion and the Primitive Methodists Its latest statistics (1881 2) show 1149 travelling preachers, 185,312 members, and 383 350 Sunday scholars [4]

Bible Christians —The Primitive Methodists sprang up in the midland counties the Bible Christians in Cornwall These closely resemble the "Primitives in their character and spirit Their founder was a Cornish local preacher called O Bryan Hence the Connexion is often known as the Bryanites, and Cornish emigrants have propagated this denomination widely in the colonies The Conference is composed of ten superintendents of districts, the president and secretary of the preceding Conference, lay delegates, one from each district meeting and as many of the travelling preachers as are allowed by their respective district meetings to attend In general it may be said that the ministerial and lay members of the Conference are about equal in number The returns for 1881–82 showed in England (chiefly the west and south of Eng

---

[1] The best authority as to American Methodism is Dr Abel Stevens's *History* in 6 vols The statistics are given in the *Methodist Year Book* New York 1882

[2] See *Jubilee Volume of the New Connexion* also the *General Rules* and the *Minutes of Conference* 1881 published at the New Connexion Book Room

[3] See *Foundation Deed of the United Methodist Free Churches* also *Minutes of Conference* 1881 119 Salisbury Square

[4] See John Petty *History of the Primitive Methodist Connexion*, also *Minutes of Conference* 1881, 6 Sutton Street London E

land) and in the Channel Islands 186 itinerant preachers, 21,209 members (besides 690 on trial), and 36,335 Sunday scholars In Canada the number of members was 6652, and in Australia and New Zealand 3671 [1]

The Wesleyan Reform Union is an aggregate of local Methodist secession churches, loosely held together by a Conference, and is one of the results of the great Methodist disruption of 1851–52 The returns for 1881–82 showed 18 ministers and 7728 members

Œcumenical Methodist Conference —This Conference was held in City Road Chapel, London, in September 1881 Representatives were present from all the Methodist bodies throughout the world, and it was estimated that these represented not less than 5,000,000 of members and 20,000,000 of population Whilst in church organization these bodies differed, as has been shown above, in doctrine and in respect of their purely spiritual discipline and means of grace, they were all agreed in principal matters The Conference was entirely practical in character The object was to promote zeal and union among the constituent bodies as to all practical points of Christian sympathy and activity, at home and abroad, and especially as to home mission work, general philanthropy, Christian education, and a Christian use of the press There were 400 representatives present from the Methodist bodies in all parts of the world [2]

Welsh Calvinistic Methodists —Between the Methodism of Wales and that of England there was never any other than incidental connexion Indeed although the name of the Welsh movement was borrowed from the English, not only was Welsh Methodism quite independent in its origin, but in reality its beginning, as an evangelical movement, was earlier than that of English Methodism From Wesleyan Methodism, furthermore, Welsh Methodism was throughout distinguished by the fact that it was Calvinistic in its doctrine For some years Whitefield's name was placed by the leaders of Welsh Methodism at the head of their movement, but the connexion was not at any time much more than nominal, Whitefield being, indeed, too often and too long together in America to exercise any real presidency over the Methodism of the Principality

Distinction, however must be made between Welsh Methodism as an evangelistic movement and as an organization In its later and distinctly organized form, its main elements date from 1811, while the actual unity and the final consolidation of the organization date from so recent a period as 1864 At that date we find the Calvinistic Methodism of North and of South Wales for the first time united in a common organization and government, and brought under the supreme control of one "General Assembly

The spiritual awakening from which Welsh Calvinistic Methodism derived its earliest inspiration and impulse began in 1735 and 1736, almost contemporaneously and quite independently, in three different counties of South Wales Howell Harris, a gentleman of some position, born and bred at Trevecca in the parish of Talgarth, county of Brecon, is the most prominent name connected with early Welsh Methodism His first strong religious convictions and impulses date from 1735 He was sent to Oxford in the autumn of that year to ' cure him of his fanaticism, but remained only one term On his return to Wales he began to exhort and preach in private houses and in such buildings as he could obtain the use of, being then and throughout his life a simple layman Of learning or theology he had but little, but he was an extemporary preacher of prodigious vehemence, and often of overwhelming power and pathos While Harris was thus preaching in the county of Brecon, Daniel Rowlands had been spiritually awakened at Llangeitho in Cardiganshire, the two men knowing nothing whatever of each other Rowlands was an ordained clergyman, of some learning and of great eloquence He was a pulpit orator, and carefully prepared his powerful discourses In Pembrokeshire, again, in that same year 1735–36, Howell Davies began to preach the same doctrine in the same spirit as the other two preachers, and with effects scarcely if at all, less remarkable The work thus begun in three distinct centres within the space of one year was in strict connexion with the Established Church, and so continued to be throughout the last century These single minded preachers pursued their work in Wales knowing nothing of the parallel work which Whitefield had just begun in England In 1738, however, Whitefield, in the west of England, heard of Howell Harris, and in that year the two revivalists met in Cardiff In 1739 Howell Harris had begun to extend his preaching tours far and wide, visiting not only South but North Wales, and, wherever he went, founding religious societies in connexion with the Church of England, of a character resembling those called Dr Woodward's societies, which had long been in existence throughout England, the chief difference being that the Welsh societies were "evangelical ' Calvinistic, and revivalist It was in the same year that Wesley founded his society in England In 1742 the clergymen connected with the Welsh movement were ten in number, and there were labouring in concert with these forty lay "exhorters, ' as they were called In that year the first "association" of Welsh Calvinistic Methodists was held at Waterford or Watford, in Glamorganshire Whitefield consented to preside, and joined his preaching to that of the Welsh evangelists The first Calvinistic Methodist Conference was held at Waterford, under Whitefield's presidency, on January 5, 1743, eighteen months earlier than Wesley's first Conference For a short time the Calvinistic Methodism of Wales was linked to that of England After 1748, however, Whitefield ceased to act as in any sense the official head of the Calvinistic Methodists of England, and their organization, always loose, was gradually dissolved

There was no Wesley in Welsh Methodism, and accordingly there was no organic unity among the societies of earlier Welsh Methodism Each local society was under the care of an "exhorter, ' an unpaid layman A number of these local societies were grouped together into a district, over which an "overseer had charge He also was usually an unpaid layman, although exercising many of the functions of a spiritual pastor Sometimes, however, as in the case of Rowlands, he was a parish clergyman The societies attended their parish churches and there received the sacraments The meeting or preaching houses for the societies were vaguely called 'houses for religious purposes '

In 1751 Howell Harris ceased to itinerate and retired to Trevecca. From this time his leadership in the Methodist movement seems to have come to an end, and the movement languished for many years after Not till 1762 is any 'revival chronicled In 1763 Rowlands was obliged to quit his curacy at Llangeitho and leave the Established Church His people built him a chapel He thus, after 1763 became a Dissenting minister, and, retaining his fame and much of his power to the end of his course, he died in 1790

Fifty years had now passed since the first societies of Welsh Methodism had been established by Howell Harris, and the movement, instead of having grown to strength and maturity, appeared to have spent its force, almost in all directions, at least so far as any outward signs could show But the Rev Thomas Charles of Bala was to be one of the chief means of reviving it He, like the earlier Methodists, was a churchman he had taken his degree at Oxford and served a curacy in Somersetshire The doors of the Established Church having been closed against him because of his style of preaching, he joined the Welsh Methodists in 1785, and his first sphere of marked influence was in North Wales In 1791 he took a leading part in a great revival of which Bala was the centre From this period may be dated the second spring of Welsh Calvinistic Methodism, from which its later successes were to grow Charles zealously and successfully promoted the establishment of "circulating schools' and of Sabbath schools He was, in fact, the soul of the great Christian educating movement in Wales which began in the last decade of the 18th century, and it was through his earnest zeal in seeking to provide Bibles for his Welsh schools, especially the Sunday schools, that the British and Foreign Bible Society was established Though Methodism came then to be effectually rooted in the soil of the Principality, it was not till 1811 that the Welsh Calvinists took that step in the direction of ecclesiastical independence which the English Wesleyans had taken sixteen years before by calling their preachers to the official position of pastors and ordaining them to administer the sacraments

From 1790 till almost the present time the work of gradually moulding the constitution of Welsh Calvinistic Methodism has proceeded The "rules regarding the proper mode of conducting the quarterly association were drawn up by Charles and agreed upon in 1790 In 1801 the *Order and Form of Church Government and Rules of Discipline* were published In 1811, as has been shown, ministerial ordination was initiated In 1823 the *Confession of Faith* was promulgated And in 1864, as has been already mentioned, the first "General Assembly was held, and the two associations of North and South Wales respectively were united into one body The constitution is now a modified Presbyterianism, each church managing its own affairs subject to successive appeal to the monthly meeting of the county and the quarterly association of the province, while the latter body may refer the decision to the annual General Assembly

The Welsh Methodists (or Welsh Presbyterians, as they are now often called) have two theological colleges, one at Bala and the other at Trevecca They have also a foreign missionary society, with missions in Brittany, among their congeners of the Celtic race, and in Bengal

In recent years this church has made great progress In 1850 the number of members was 58,678, in 1870 it was 92,735, and in 1880 the returns showed 1174 churches, 118,979 communicants, 185,635 Sunday scholars The number of ministers is not officially given, but is estimated at 600 The North and South Wales associations are now also known as synods [3] (J H RI)

---

[2] See *Proceedings of First Methodist Œcumenical Conference*, Wesleyan Book Room, City Road.

[3] See W Williams, *Welsh Calvinistic Methodism a Historical Sketch* *The Life and Times of Howell Harris* , Tyerman, *Life of the Rev George Whitefield*, *The Diary of the Calvinistic Methodists* 1882

METHODIUS, the apostle of the Slavs, was a native of Thessalonica, and was born about the year 825. His nationality is unknown, but most probably he was a Græcized Slav; the family of which he was a member appears to have been one of considerable social distinction, and he himself had already attained high official rank in the government of Macedonia before he determined to abandon his secular career and embrace the monastic life. His younger brother Constantine (better known as Cyril, the name he adopted at Rome shortly before his death) had also distinguished himself as a secular "philosopher" in Constantinople before he withdrew to the cloister and to solitude. Constantine about 860 had been sent by the emperor Michael III. to the Khazars, in response to their request for a Christian teacher, but had not remained long among them; after his return to within the limits of the empire, his brother and he laboured for the instruction of the Slavonic or Slavonicized population, especially by means of translations of the Scripture lessons and the liturgical books used in Christian worship. About the year 863, at the invitation of Rastislav, king of "Great Moravia," who desired the Christianization of his subjects, but at the same time that they should be independent of the Germans, the two brothers went to his capital (its site is unknown), and, besides establishing a seminary for the education of priests, successfully occupied themselves in preaching in the vernacular and in diffusing their religious literature. After four years they seem to have received and accepted an invitation to Rome from Pope Nicholas I., who had just been engaged in his still extant correspondence with the newly converted Bulgarian king; his death occurred before their arrival, but they were kindly received by his successor Hadrian II. Constantine died in Rome, but Methodius, after satisfying the pope of his orthodoxy and obedience, went back to his labours in "Moravia" as archbishop of Pannonia. His province appears to have been, roughly speaking, co-extensive with the basins of the Raab, Drave, and Save, and thus to have included parts of what had previously belonged to the provinces of Salzburg and Passau. In 871 complaints on this account were made at Rome, nominally on behalf of the archbishop of Salzburg, but really in the interests of the German king and his Germanizing ally Swatopluk, Rastislav's successor; they were not, however, immediately successful. In 879, however, Methodius was again summoned to Rome by Pope John VIII., after having declined to give up the practice of celebrating mass in the Slavonic tongue; but, owing to the peculiar delicacy of the relations of Rome with Constantinople, and with the young church of Bulgaria, the pope, contrary to all expectation, ultimately decided in favour of a Slavonic liturgy, and sent Methodius (880) back to his diocese with a suffragan bishop, and with a letter of recommendation to Swatopluk. This suffragan, a German named Wiching, unfortunately proved quite the reverse of helpful to his metropolitan, and through his agency, especially after the death of John VIII. in 882, the closing years of the life of Methodius were embittered by continual ecclesiastical disputes, in the course of which he is said to have laid Swatopluk and his supporters under the ban, and the realm under interdict. The date of the death of Methodius is variously given; the most trustworthy tradition says that it took place on April 6, 885. He was buried at Welehrad (probably Stuhlweissenberg). The Greek Church commemorates St Cyril on February 14 and St Methodius on May 11; in the Roman Church both are commemorated on March 9.

See Schafarik's *Slawische Alterthumer*, where the original authorities are fully referred to. The subject of the present notice is most probably not to be identified with the Methodius, a painter and monk, who, according to a well known legend, converted Boris of Bulgaria by means of a picture of Christ's second coming.

METHYL, a chemical term which until lately was used in two radically different senses, namely, as designating either the atom group CH_3, which in numberless chemical formulæ figures as a "radical" (compare CHEMISTRY, vol. v. p. 552), or a gaseous substance of the same composition, which, however, nowadays is generally called "dimethyl," to distinguish it from the radical. A gas of the composition and the specific gravity ($C_2H_6 - H_2 = 15$) corresponding to C_2H_6 can be produced in two principal ways,—first, by the decomposition of zinc ethyl by water (Frankland)—

$$Zn(C_2H_5)_2 + 2OH \cdot H = Zn(OH)_2 + C_2H_5H\ ,$$

and, secondly, by the electrolysis of acetate of potash solution (Kolbe), we have virtually

$$2CH_3 \cdot COOH = (CH_3)_2 + \underset{+\text{pole}}{2CO_2} + \underset{-\text{pole}}{H_2}$$

These two gases used to be distinguished as two different substances,—Frankland's being looked upon as hydride of ethyl, $C_2H_5 \cdot H$, Kolbe's as "real methyl" $(CH_3)(CH_3)$, until Schorlemmer proved their identity by showing that both, when treated with chlorine, yield the same identical chloride of ethyl, $C_2H_5 \cdot Cl$. This confirmed the now generally adopted notion that the radical ethyl itself is nothing but methylo-methyl, $H_3C—CH_2{}^*$, so that the filling up of the gap* by an H must necessarily produce "hydride of ethyl" and "dimethyl" in one. The "true methyl" which chemists used to dream of, and which, when treated with chlorine, would yield two CH_3Cl's analogous to $HH + ClCl = HCl + HCl$, does not, and according to our present knowledge cannot, exist. A quasi apology for it is "marsh gas," CH_4, the principal component of the gas mixture which bubbles up from any marshy pond when its mud is stirred up with a stick. It is always produced when vegetable matter decays in the presence of water, and in the relative or absolute absence of air. What everybody knows as "fire damp" is nothing but a (necessarily explosive) mixture of air with impure marsh gas, produced in the constantly progressing metamorphosis of the coal deposits; in certain districts streams of marsh gas are issuing forth from cracks in the earth; the "holy fire" of Baku is such a marsh gas spring, which, having once caught fire by accident, continues burning to this day. Perfectly pure marsh gas can only be obtained from zinc methyl, $Zn(CH_3)_2$, by its decomposition with water (*vide supra*); a nearly pure preparation is procurable by heating a mixture of acetate of potash or soda and caustic alkali to dull redness:—

$$\underset{\text{Acetate}}{CH_3 \cdot COONa} + NaOH = \underset{\text{Carbonate}}{Na_2CO_3} + CH_3H$$

Marsh gas can be prepared synthetically by the action of bisulphide of carbon vapour and sulphuretted hydrogen (both producible from their elements) on red hot copper, $CS_2 + 2H_2S + 8Cu = 4Cu_2S + CH_4$ (Berthelot). A mixture of marsh gas and chlorine, when exposed to direct sunlight, explodes with formation of hydrochloric acid and charcoal. In diffuse daylight only part of the hydrogen is eliminated and "replaced" by its equivalent in chlorine, which in general leads to the formation of four bodies: $CH_3Cl = CH_4 + Cl_2 - HCl$, chloride of methyl; CH_2Cl_2, chloride of methylene; $CHCl_3$, chloroform; CCl_4, tetrachloride of carbon. Of these several chloromethanes, as they are called, the first here interests us more than any of the rest, because from it any other methyl compound can be produced by the substitution of the proper kind of radical for the Cl of the CH_3Cl. Thus, for instance, we can convert it into methyl alcohol by treating the chloride with aqueous caustic potash at 100° C. (Berthelot). This is a most important synthesis, because it is this methyl-alcohol that, in practice, always serves as the starting point in the preparation of other methyl compounds.

Methyl Alcohol.—This substance, in ordinary practice, is never made synthetically, but simply extracted from wood spirit, a commercial substance which is produced industrially in the dry distillation of wood The wood spirit is contained in the aqueous portion of the tar produced in this operation, along with acetic acid To recover both, the tar water is neutralized with lime and distilled, when the acetate remains, while the spirit distils over, along with a deal of water, which, however, is easily removed, as far as necessary, by redistillation and rejection of the less volatile parts The "crude' wood spirit, as thus obtained, is not unlike in its general properties to ordinary spirit of wine, from which, however, it is easily distinguished by its abominable smell The ordinary commercial article, besides a variable percentage of water, contains from 35 to 80 per cent of methyl alcohol the rest consists chiefly of acetone, but besides includes dimethyl acetal, $C\,H_4(OCH_3)_2$, acetate of methyl, and numerous other minor components In Great Britain large quantities of wood spirit are used for the making of methylated spirit, a mixture of ordinary spirit of wine with one ninth of its volume of wood spirit, which is allowed to be sold duty free for the preparation of varnishes, and for other industrial purposes In former time here as elsewhere, wood spirit itself used to be employed as a cheap substitute for spiritus vini, but this is no longer so, since the aniline colour industry has created a large demand for pure methyl alcohol Hence in some Continental works the wood spirit, instead of being sent out as such, is being worked up for its components, by the following sequence of operations —(1) dehydration by lime, (2) heating, under an inverted condenser, with caustic soda, to convert the acetate into hydrate of methyl, (3) destruction of the bad smells by mild oxidation, (4) distillation in a kind of Coffey's still, whereby it is split up into approximately pure alcohol, acetone, and "tails

The new industry led to the invention of the following technical methods for the determination in a given spirit of the percentages of real methyl alcohol and of acetone

The alcohol is determined by saturating 5 c c of the spirit with hydriodic acid (volatilization of alcohol and iodide of methyl being avoided by means of a cold water bath and an inverted condenser), and the product poured into water Iodide of methyl separates out as a heavy oil which is measured as it is According to direct trials 5 c c of pure methyl alcohol yields 7 45 c c of crude iodide (Krell Kramer and Grodzky)

For the determination of the acetone the following reagents are required (Kramer) —(1) a solution of iodine prepared by dissolving $I_2=254$ grammes of iodine by means of (say) 500 grammes of iodide of potassium in water and diluting to 1 litre (2) a solution of caustic soda containing twice (NaOH) grammes per litre (3) alcohol free ether Ten c c of the soda are placed in a graduated cylinder and mixed intimately, first with 1 c c of the spirit then with 5 c c of the iodine solution Iodoform separates out (if acetone is present) in minute yellow crystal plates, this product is 'shaken out' by means of 10 c c of ether and determined by evaporating an aliquot part of the ethereal layer in a tared watch glass to dryness and weighing the residue $C_3H\ O$ yields CHI_3 hence 1 part of iodoform indicates 0 28 parts of acetone

The formula of methyl alcohol and its true chemical character were correctly ascertained by Dumas and Péligot as early as 1834, yet pure methyl alcohol may be said to have been an unknown substance until 1852, when Wohler taught us to prepare it, by first extracting the CH_3 of the CH_3OH in the wood spirit as oxalate of methyl, and then decomposing the (purified) oxalate with water

The most convenient raw material to use nowadays is the commercial "pure alcohol if wood spirit is employed it had better first be purified by distillation over caustic soda (*vide supra*) The formation of the oxalate then is best effected (according to Alexander Watt) as follows —500 grammes of oxalic acid crystals are mixed with 200 c c of oil of vitriol, then 500 c c of the spirit are added, the whole kept for a time at 80° C, and then allowed to stand cold for twenty four hours

The large crop of oxalate crystals—partly $(CH_3)_2C_2O_4$ partly $CH_3\ H\ C_2O_4$—is separated from the liquor by pressure and subsequent drying over vitriol, and then decomposed by distillation with water

The aqueous alcohol thus obtained is dehydrated by the well known methods used in the preparation of ordinary absolute alcohol

According to Kramer, a purer preparation than Wohler's is obtained by extracting the methyl as formiate instead of as oxalate, which is easily effected by digesting the wood spirit with a formic acid of 1 22 specific gravity, and purifying the formic ether by fractional distillation This ether boils at 32°, the oxalate at 161° C hence a proper combination of the two methods should be infinitely superior to either What now follows must, in general, be understood to refer to Wohler's preparation

Pure methyl alcohol is a colourless liquid similar in its general properties, in its behaviour to other chemically inert liquids, and in its action as a solvent to ordinary absolute alcohol, from which, however, it differs by the entire absence from it of all spirituous odour A preparation which smells of wood spirit may be condemned at once as impure According to H Kopp, its specific gravity is 0 8142 at 0° C and 0 7997 at 16° 4 If the volume at *t*° be V, then (from 0° to 61°)

$$V = 1 + \ 0001134t + 1\ 364 \times 10^{\ 6}t^2 + 8\ 741 \times 10^{\ 9}t^3$$

The boiling point is 64° 6 to 65° 2 The tension-curve was determined by Regnault and by Landolt, but the results of the two observers do not agree except (approximately) at P = 760 mm Methyl alcohol has quite a characteristic tendency to "bump badly on distillation, which, however, can be prevented by addition of a small fragment of tin sodium, which produces a feeble but sufficient current of hydrogen Its specific heat is 6713 latent heat of vapour, 26 4, combustion heat, 5307 per unit weight (Favre and Silbermann) The refractive index for the D (sodium) ray is 1 3379 ± 0013 for 10° ∓ 5 C (Dale and Gladstone)

Methyl alcohol mixes with water in all proportions with contraction

Since Wohler's discovery a table for the specific gravities of aqueous methyl alcohols has been constructed experimentally by A Dupre but unfortunately his alcohol boiled at 58° 7 and consequently must have been something different from what generally goes by this name

In its chemical reactions methyl alcohol, $CH_3\ OH$, is very similar to ordinary (ethyl) alcohol, $C\,H_5\ OH$, and consequently in the same sense as the latter, analogous to water, H OH Thus, for instance, metallic sodium and potassium dissolve in either alcohol with evolution of hydrogen and formation of ethylates or methylates of the alkali metals Example—

$$CH_3OH + Na = CH_3\ ONa + \tfrac{1}{2}H_2$$

The two methylates crystallize from the solution with crystal alcohol, which can be driven off in an atmosphere of hydrogen by heat, without decomposition of the salts themselves Water at once decomposes them into caustic alkali and alcohol, $CH_3\ ONa + H\ OH = NaOH + CH_3OH$. Yet the reverse reaction takes place when the alcohol is treated with a large excess of caustic soda

The action of acids on methyl alcohol is in general quite analogous to that on, for instance, caustic soda, with this important difference, however, that what in the case of NaHO goes on so readily in aqueous solutions with $CH_3\ OH$ succeeds only under circumstances precluding the accumulation of water In these circumstances we have, for instance,

$$(1)\ \mathrm{Cl}\overline{\mathrm{H}+\mathrm{OH}}\ \mathrm{CH_3} = \mathrm{H_2O} + \mathrm{Cl}\ \mathrm{CH_3},$$

$$(2)\ \underset{\text{Acetic acid}}{(\mathrm{C_2H_3O_2})}\overline{\mathrm{H}+\mathrm{OH}}\ \mathrm{CH_3} = \mathrm{H_2O} + \underset{\text{Acetic ether}}{\mathrm{C_2H_3O_2}\ \mathrm{CH_3}}$$

and so on with all monobasic acids A dibasic acid XHH may act as $(X)H_2$ or as $(XH)\ H$, thus, for instance,

$$(3)\ \underset{\text{Oxalic acid}}{(\mathrm{C_2O_4H})}\overline{\mathrm{H}+\mathrm{OH}}\ \mathrm{CH_3} = \mathrm{H_2O} + \underset{\text{Methyl oxalic acid.}}{\mathrm{C_2O_4}\ \mathrm{HCH_3}},$$

$$(4)\ (\mathrm{C_2O_4})\mathrm{H_2} + 2\mathrm{OH}\ \mathrm{CH_3} = 2\mathrm{H_2O} + \underset{\text{Methyl ox}}{\mathrm{C_2O_4}\ (\mathrm{CH_3})_2},$$

A tribasic acid forms two methyl acids and one neutral ether, we have, for instance,

(5) (From PO_4H_3), $PO_4(CH_3)H_2$, $PO_4(CH_3)_2H$, $PO_4(CH_3)_3$

It would, however, be a great mistake to suppose that whether, for instance (Ex 3 and 4), the monomethyl or the dimethyl compound is formed depends on the quantity of methyl alcohol employed per unit of acid This depends far more largely on other conditions, as will be illustrated in next paragraph The methyl salts of oxygen acids are called esters, in opposition to the chloride, bromide, iodide, sulphide, and oxide, which are set apart as ethers Broadly speaking, ethers are not, while esters are, readily decomposed by water into their congeners, but the nitrate $CH_3\ NO_3$ behaves in this respect like an ether

Action with Sulphuric Acid—Methyl alcohol mixes with oil of vitriol with considerable evolution of heat and (always only partial) conversion of the two ingredients into methyl sulphuric acid Equal volumes of acid and alcohol give a good yield To prepare pure methyl sulphates, dilute the mixture largely with water, avoiding elevation of temperature (which would regenerate the ingredients), and saturate with carbonate of baryta Filter off the sulphate of baryta to obtain a solution of the pure methyl sulphate $SO_4\ CH_3\ ba$ (where ba = ½Ba = 1 *eq*), from which this salt is easily obtained in crystals From the baryta salt any other methyl sulphate is readily obtained by double decomposition with a solution of the respective sulphate, the acid itself, for instance, by means of sulphuric acid At higher temperatures the reaction between vitriol and methyl alcohol results in the formation of methyl ether, $(CH_3)_2O$, or of normal sulphate of methyl, $(CH_3)_2SO_4$ The ether is a gas condensable into a liquid which, under pressure of one atmosphere, boils at − 21° C

The gas dissolves in about one thirty seventh of its volume of water, far more largely in alcohol and in ether most abundantly in oil of vitriol, which dissolves about six hundred times its volume of methyl ether gas thus affording a very handy means for storing up the gas for use The solution needs only be diluted with its own volume of water to be broken up into its components (Erlenmeyer)

Liquefied oxide of methyl is now being produced on the manufacturing scale, and sold as a powerful refrigerating agent One part of sulphuric acid is mixed with a little over one part of dehydrated wood spirit, and the mixture heated to 125° to 128° C (130° being carefully avoided), when methyl ether goes off When the mixture is exhausted, more wood spirit is added to the residue so as to re establish the original specific gravity (of 1 29), and the heating resumed, which again furnishes a supply of the gas, and so on This proves that the process is not, as used to be supposed, one of mere dehydration, but a cycle of reactions analogous to those in the ordinary process of etherification, as shown by the equations —

(1) $SO_4H_2 + CH_3OH = SO_4\ HCH_3 + H_2O$

(2) $SO_4\ H\ CH_3 + H\ O\ CH_3 = SO_4HH + CH_3\ O\ CH_3$

The ester $SO_4(CH_3)$ though obtainable by distillation of the alcohol with 10 parts of vitriol is more conveniently prepared from pure methyl sulphuric acid by distillation in vacuum at 130° 140° C, thus —$2SO_4CH_3\ H = SO_4H_2 + SO_4(CH_3)_2$ It is a colourless liquid, smelling like peppermint specific gravity 1 327 at 18°, it boils at 187° to 188° C

Chloride of methyl, CH_3Cl, readily produced by the action of hydrochloric acid gas and hot methyl alcohol (preferably in the presence of chloride of zinc as an auxiliary dehydrator), is a gas which, under ordinary pressure, condenses into a liquid at − 23° C The gas, at ordinary temperatures (though very readily soluble in alcohol), is only sparingly absorbed by water, which, however, at 6° unites with it into a solid hydrate Condensed methyl chloride has become an article of commerce, being largely produced from trimethylamine (*vide infra*) and used as a powerful frigorific agent, as well as for the extraction of perfumes from flowers Regarding nitrite of methyl, $NO—O—CH_3$, its interesting isomeride nitromethane, $O_2N—CH_3$, and nitrate of methyl, NO_3CH_3, we must refer to the handbooks of organic chemistry

Iodide of methyl, CH_3, is obtained by distilling methyl-alcohol with hydriodic acid, which latter is best produced off hand by addition to the alcohol of iodine and amorphous phosphorus It is a colourless liquid of 2 269 specific gravity, boiling at 42° 5 C, insoluble in water

Organic Methyl Esters—The more volatile ones are in general easily obtained by distillation of the respective acid with methyl alcohol, or with methyl alcohol and oil of vitriol (virtually $SO_4\ H\ CH_3$), the less volatile ones more conveniently by passing hydrochloric acid gas into a methyl alcoholic solution of the acid We have no space for the individual substances, but the salicylate $C_7H_5O_3\ CH_3$ may just be named as being the principal component of the essential oil of *Gaultheria procumbens* (wintergreen oil)

Methylamines—The general result of the action of ammonia on an ester is the formation of alcohol and acid amide Example—

$$\underset{\text{Acetate of methyl}}{(C_2H_3O)-\overline{O—CH_3+H}}NH_2 = CH_3\ OH + \underset{\text{Acetamide}}{C_2H_3O\ NH_2}$$

With iodide of methyl this reaction is an obvious impossibility, what really takes place (as A W Hofmann has shown for this and all analogous cases) is that the iodide unites with the ammonia into the HI compound $HI\ NH_2CH_3$ of a base NH_2CH_3, which can be separated from the acid by distillation with caustic potash, and when thus liberated presents itself as a gas surprisingly similar (almost to identity) to ammonia The analogy extends to the action on iodide of methyl, which, in the case of methyl amine, NH_2CH_3, leads to the formation of dimethylamine, $NH\ (CH_3)_2$, and from the latter again trimethylamine, $N(CH_3)_3$, can be prepared by a simple repetition of the operation These three amines are closely analogous in their chemical character to ammonia, the points of difference becoming the more marked the greater the number of (CH_3) s in the molecule Trimethylamine, having lost all its ammonia hydrogen, cannot possibly act upon iodide of methyl like its analogues What it really does is to unite with the iodide into "iodide of tetramethyl ammonium," $I\ N(CH_3)_4$, analogous to iodide of ammonium, INH_4, we should say, if it were not the reverse, because the organic iodide (unlike its prototype, which is an ammonium compound only in theory), when treated with moist oxide of silver (virtually with AgOH), really does yield a solution of a true analogue of caustic potash in the shape of hydroxide of tetramethyl ammonium, $N(CH_3)_4\ OH$

In regard to the actual preparation of these several bodies, which is not so simple as might appear from our exposition of their mutual relations, we must refer to the handbooks of organic chemistry But we must not omit to state that trimethylamine, which only the other day was never seen outside a chemical museum, is now being manufactured on a large scale, and promises to play an important part in industrial chemistry The waste liquors obtained in the distillation of alcohol from fermented beet-root molasses serve as a raw material for its preparation These liquors, when evaporated to dryness and subjected to dry distillation, yield, besides tar and gases, an aqueous liquid containing large quantities of ammonia, acetonitrile, methyl-alcohol, and trimethylamine This liquor is neutralized with sulphuric acid, and distilled, when the nitrile and the methyl alcohol distil over, to be recovered by proper methods From the mixed solution of the sulphates of ammonia and trimethylamine the former is separated out as far as possible by crystallization, the mother-liquor is distilled with lime; the volatile bases are absorbed in hydrochloric acid, the hydrochloric solution is evaporated, and the sal ammoniac which comes out at first is, as far as possible, fished out The last mother liquor is evaporated to dryness, and in this form represents commercial trimethylamine hydrochlorate It is this product which serves for the preparation of methyl chloride (*vide supra*), the process being founded upon the fact that a concentrated solution of the salt, when heated, breaks up $3HCl\ N(CH_3)_3$ into $2N(CH_3)_3$ of free trimethylamine + $NH_2\ CH_3HCl$ of hydrochlorate of monomethylamine and $2CH_3Cl$ of methyl chloride

These processes are being carried out industrially by Vincent in France But this base trimethylamine seems destined to do more than provide us with a new refrigerating agent The attempt has been made—it would appear, with success—to utilize it for the preparation of pure carbonate of potash from native chloride of potassium, just as ordinary ammonia, in the famous ammonia soda process, serves for the conversion of common salt into soda ash

Methyl Cyanides —There are two distinct bodies which by composition and by synthesis are both $CH_3 + NC$ they are named "acetonitrile (formerly called simply cyanide of methyl) and isocyanide of methyl or methylcarbamine respectively

Acetonitrile was discovered by Dumas in 1847 It may pared by the distillation of a mixture of methylsulphate and cyanide of potassium, but is obtained more easily and in a purer state by distilling acetamide with phosphoric anhydride Acetate of ammonia may be used instead of the amide, but it does not work so well

$CH_3\ CO\ O(NH_4)$	$CH_3\ CO\ (NH_2)$	$CH_3\ CN$
Acetate of NH_3	Acetamide	Nitrile
= A (say)	$= A - H_2O$	$= A - 2H_2O$

It is a colourless liquid of a pungent aromatic odour, with specific gravity 805 at 0° and boils at 82° C When heated with aqueous potash (at the wrong end of a condenser) it breaks up with formation of ammonia and acetate of potash Whence we conclude that the methyl is combined more directly with the carbon of the cyanogen, thus

$$N\{\overline{C—CH_3}\} + 2H_2O = NH_3 + \underset{\text{Acetic acid}}{CH_3\ COOH}.$$

This conclusion is supported by the action on the nitrile of nascent hydrogen, which leads to the formation of ethylamine, thus (Mendius) —

$$NC—CH_3 + 4H = \underset{\text{Ethylamine}}{H_2N—CH_2CH_3}$$

In either case we pass from a monocarbon to a dicarbon body, virtually from methyl to ethyl alcohol

The isocyanide is prepared by heating iodide of methyl with cyanide of silver (CH_3I, $2NCAg$) and ether in a sealed up tube to 130° to 140°, to produce the crystalline body $AgNC + NCCH_3$ (and AgI) The double cyanide, when distilled with some water and cyanide of potassium, breaks up into its components —the $NCAg$ forming $(NC)_2AgK$ and the cyanide of methyl distils over It is a colourless liquid, characterized by quite an unbearably irritating and sickening smell The specific gravity is 756 at 14°, the boiling point 59° C It combines with hydrochloric acid into a crystalline salt which is readily decomposed by water into methylamine and formic acid Whence we conclude that in this case the cyanogen is tied to the methyl by its nitrogen, thus —

$$C\{N—CH_3\} + 2H_2O = \underset{\text{Formic acid.}}{H\ COOH} + \underset{\text{Methylamine}}{NH_2\ CH_3}$$

The methyl here remains methyl, being separated by an N from the cyanogen carbon, which latter passes into formic acid

We must not close this section without at least referring to the *methylphosphines*, as being a set of bodies related to PH_3 (phosphine) as the methylamines are to NH_3 (ammonia) and similar to these in their chemical character, in so far as they are bases The points of difference between the two series are of pretty much the same sense as those between the two prototypes Thus, for instance, while trimethylamine $N(CH_3)_3$ is a strong base but inert to oxygen gas, trimethylphosphine is a relatively feeble base, but in contact with air greedily absorbs oxygen with formation of an oxide $P(CH_3)_3O$, the like of which in the nitrogen series has no existence

Sulphur Compounds of Methyl —Substances analogous to methyl-alcohol and methyl ether respectively can be obtained by the distillation of methyl sulphate of potassium with strong solutions of the potassium sulphides KHS and K_2S respectively The body $CH_3\ SH$ is known as methyl-mercaptane, the other $(CH_3)_2S$ as sulphide of methyl Both are very volatile stinking liquids. Sulphide of methyl claims a special interest as being the starting point for the preparation of an important class of bodies called trymethyl sulphine compounds The sulphide $(CH_3)_2S$ readily unites with the iodide CH_3I into crystals of iodide of trimethyl sulphine, $(CH_3)_3S\ I$, a substance which is closely analogous in its chemical character to the iodide of tetramethyl ammonium. Moist oxide of silver, for instance, converts it into a strongly basic hydrate, $S(CH_3)_3\ OH$, which in its avidity for acids almost beats its analogon in the nitrogen family An investigation of its salts was published by Crum Brown and Blaikie

Methyl Arsenides —Arseniferous bases constituted like mono or di methylamine (bodies such as AsH_2CH_3, analogous to $NH_2\ CH_3$) do not seem to exist. What we do know of are—(1) a trimethylarsine and the iodide and the hydroxide of tetramethylarsonium, —$As(CH_3)_3$, $As(CH_3)_4I$ and $As(CH_3)_4OH$,—bodies discovered by Cahours and Riche, (2) a whole series of monomethylic bodies, $As(CH_3)X_2$ (where $X = Cl$, Br, or $X_2 = O,S$), discovered by Baeyer in 1857, (3) the kakodyle compounds, a series of bodies, $As(CH_3)_2\ X$ or $As(CH_3)_2\ X_3$, which were discovered and investigated by R. Bunsen in 1842 This great investigation marks an epoch in the history of organic chemistry, and our article would not be complete without at least a short summary of its results Bunsen started in his investigation with a liquid which had been obtained by Cadet as early as 1760, by the dry distillation of equal parts of white arsenic and anhydrous acetate of potash and which nobody cared to investigate because it emits fumes which have an indescribably sickening smell and an intensity of poisonous action, compared with which that of white arsenic itself appears insignificant It was reserved for Bunsen to attack this awful substance and force it to give an account of itself. According to Bunsen Cadet s liquid is substantially an oxide, $(AsC_2H_6)_2O$ which has strongly basic properties, readily exchanging its O for Cl_2 &c To obtain the pure substance, the liquor is distilled with corrosive sublimate and hydrochloric acid, which in the first instance yields the pure muriate of the base $As(CH_3)_2Cl$, in the form of a liquid volatile above 100° into vapours which take fire spontaneously in air From this chloride of kakodyle the pure oxide is obtained by distillation with caustic potash The pure oxide emits no fumes its specific gravity is 1 462, it boils near 150° A mixture of its vapour with air detonates at 50° C From the chloride again Bunsen obtained the free radical *kakodyle*, $(AsC_2H_6)_2$ by treatment with metallic zinc in a special apparatus, so constructed that all the several operations involved could be carried out without bringing the contents in contact with air,—a necessary precaution, because kakodyle is a liquid which takes fire in air spontaneously even at ordinary temperatures Pure kakodyle is a heavy colourless liquid boiling at about 170° C, and freezing at −6° When exposed to oxygen or chlorine it suffers destructive combustion, but on slow access of air it is oxidized into its oxide $(AsC_2H_6)_2O$, and kakodylic acid, with chlorine water it unites into the chloride which it came from, it also unites directly with sulphur and other elements, in short, it is exactly to kakodyle compounds what potassium is to potash and potash salts, a true organic element, as Bunsen himself put it This discovery of Bunsen s was greeted with an enthusiasm which it is difficult in these days to realize With us now, a radical is intrinsically a fiction it was different in 1842 By the isolation of kakodyle the 'radical notion suddenly rose from an unproved hypothesis to the rank of a theory based on experiment Still, however much our theoretical notions may shift, Bunsen s research will stand as a piece of monumental scientific work.

Kakodylic acid, $As\ O\ (CH_3)_2\ OH$, is most conveniently prepared from the oxide by addition of water and oxide of mercury,—$H_2O + 2HgO$ supplying the $H_2 + O_3$ required for $1(AsC_2H_6)_2O$ This is a crystalline monobasic acid, soluble in water Unlike the kakodylides of the $As\ X_3$ type, it has no smell, and is no very violent poison It takes six grains of it to kill a rabbit

Metallic Methides —Examples of these are—$Sb(CH_3)_3$, $Sb(CH_3)_5$, $Mg(CH_3)_2$, $Zn(CH_3)_2$ $Pb(CH_3)_4$ $Al(CH_3)_3$ $Sn(CH_3)_4$ To give an idea of the chemical character of this interesting class of bodies we choose *zinc methyl* as a representative example, and state briefly the chief points of its chemical history This body was discovered by Frankland in 1849 It is prepared by boiling iodide of methyl over granulated zinc in a flask connected with an inverted condenser, and so contrived otherwise that the contents are protected against access of moisture and oxygen Under these circumstances the two ingredients gradually unite into a non volatile and solid compound $IZn\ (CH_3)$ When this body is heated with more of iodide of methyl, it undergoes decomposition, with formation of iodide of zinc and of dimethyl gas, $I—Zn—CH_3 + CH_3I = ZnI_2 + (CH_3)_2$, which reaction to some extent takes place unavoidably in the preparation of the zinc salt, however great an excess of metal may be taken What survives needs only to be subjected to dry distillation (in the absence of air) to yield a distillate of zinc-methyl —

$$2I—Zn—CH_3 = ZnI_2 + Zn(CH_3)_2.$$

Zinc methyl is a colourless liquid of 1 386 specific gravity at 10° 5, which boils at 46° C , in contact with air it takes fire Water decomposes it at once into hydrate of oxide of zinc and marsh gas, $Zn(CH_3)_2 = Zn(OH)_2 + 2CH_3H$ Of other reactions the following may be named (1) When digested with sodium, it yields a precipitate of metallic zinc, and a double compound of itself and sodium methyl This latter unites readily with carbonic acid into acetate of soda, $NaCH_3 + CO_2 = CH_3—CO—ONa$ (Wanklyn) (2) With chloride of acetyl it forms acetone, $Zn(CH_3)_2 + 2CH_3\ CO\ Cl = ZnCl_2 + 2CO(CH_3)_2$ (Freund) (3) Under somewhat different conditions including the presence of an excess of $Zn(CH_3)_2$, a compound is produced which with water, yields tertiary butyl alcohol (Boutlerow)

$$CO(CH_3)_2 + Zn(CH_3)_2 = C(CH_3)_3\ O\ ZnCH_3 = A\,,$$
$$A + 2H\ OH = Zn(OH)_2 + CH_4 + \underbrace{C(CH_3)_3 - OH}_{\text{Tertiary alcohol}}$$

(W D)

METRONOME an instrument for denoting the speed at which a musical composition is to be performed Its invention is generally, but falsely, ascribed to Johann Nepomuk Maelzel, a native of Ratisbon (1772–1838) It consists of a pendulum swung on a pivot below the pivot is a fixed weight, and above it is a sliding weight that regulates the velocity of the oscillations by the greater or less distance from the pivot to which it is adjusted The silent metronome is impelled by the touch and ceases to beat when this impulse dies, it has a scale of numbers marked on the pendulum, and the upper part of the sliding weight is placed under that number which is to indicate the quickness of a stated note, as M M (Maelzel s Metronome) = 60, or ♩ = 72, or ♪ = 108, or the like The number 60 implies a second of time for each single oscillation of the pendulum,—numbers lower than this denoting slower, and higher numbers quicker beats The scale at first extended from 50 to 160, but now ranges from 40 to 208 A more complicated metronome is impelled by clock work, makes a ticking sound at each beat, and continues its action till the works run down, a still more intricate machine has also a bell which is struck at the first of any number of beats willed by the person who regulates it, and so signifies the accent as well as the time

The earliest instrument of the kind, a weighted pendulum of variable length, is described in a paper by Étienne Loulié (Paris, 1696, Amsterdam, 1698) Attempts were also made by Enbrayg (1732) and Gabory (1771) Harrison, who gained the prize awarded by the English Government for his chronometer, published a description of an instrument for the purpose in 1775 Davaux (1784), Pelletier, Abel Burja (1790), and Weiske (also 1790) described their various experiments for measuring musical time In 1813 Gottfried Weber, the composer, theorist and essayist, proposed a weighted ribbon graduated by inches or smaller divisions, which might be held or otherwise fixed at any desired length, and would infallibly oscillate at the same speed so long as the impulse lasted this the simplest, is also the surest the most enduring the most portable, and the cheapest invention that has come before the world, and one can but wonder that it has not been universally accepted Stockel and Zmeskall produced each an instrument and Maelzel made some slight modification of that by the former, about the end of 1812 which he announced as a new invention of his own, and exhibited from city to city on the Continent It was, as nearly as can be ascertained in 1812 that Winkel, a mechanician of Amsterdam devised a plan for reducing the inconvenient length of all existing instruments, on the principle of the double pendulum rocking on both sides of a centre and balanced by a fixed and a variable weight He spent three years in completing it, and it is described and commended in the *Report of the Netherlands Academy of Sciences*, August 14, 1815 Maelzel thereupon went to Amsterdam, saw Winkel and inspected his invention, and, recognizing its great superiority to what he called his own, offered to buy all right and title to it Winkel refused, and so Maelzel constructed a copy of the instrument, to which he added nothing but the scale of numbers, took this copy to Paris, obtained a patent for it, and in 1816 established there, in his own name, a manufactory for metronomes When the impostor revisited Amsterdam, the inventor instituted proceedings against him for his piracy, and the Academy of Sciences decided in Winkel s favour, declaring that the graduated scale was the only point in which the instrument of Maelzel differed from his Maelzel s scale was needlessly and arbitrarily complicated, proceeding by twos from 40 to 60, by threes from 60 to 72, by fours from 72 to 120, by sixes from 120 to 144, and by eights from 144 to 208 Dr Crotch constructed a time measurer, and Henry Smart (the violinist, and father of the composer of the same name) made another in 1821, both before that received as Maelzel s was known in England In 1882 James Mitchell, a Scotsman, made an ingenious amplification of the Maelzel clock work, reducing to mechanical demonstration what formerly rested wholly on the feeling of the performer Although "Maelzel s metronome" has universal acceptance, the silent metronome and still more Weber s graduated ribbon are greatly to be preferred, for the clock work of the other is liable to be out of order, and needs a nicety of regulation which is almost impossible, for instance, when Sir George Smart had to mark the traditional times of the several pieces in the Dettingen Te Deum, he tested them by twelve metronomes, no two of which beat together The value of the machine is exaggerated, for no living performer could execute a piece in unvaried time throughout, and no student could practise under the tyranny of its beat, and conductors of music, nay, composers themselves, will give the same piece slightly slower or quicker on different occasions, according to the circumstances of performance

METSU, **Gabriel**, a Dutch painter of celebrity (born in 1630, died after 1667), is one of the few artists of renown in Holland whose life has remained obscure Houbraken, who eagerly collected anecdotes of painters in the 18th century, was unable to gather more from the gossip of his contemporaries than that, as early as 1658, Metsu, at the age of forty three, submitted to a dangerous surgical operation The inference drawn by superficial readers from this statement has been that death immediately ensued A more careful perusal would have shown that Houbraken knew that Metsu had given lessons to De Musscher in 1665 Local records now reveal that Gabriel was the son of Jacques Metsu, who lived most of his days at Leyden, where he was three times married The last of these marriages was celebrated in 1625, and Jacomina Garnijers, herself the widow of a painter, gave birth to Gabriel in 1630 Connected by both his parents with art, Metsu was probably taught first by his father and then by Gerard Dow He probably finished his training under Rembrandt So far back as 1648, but a few days earlier than Jan Steen, who is said to have painted his portrait, Metsu was registered in the painters' corporation at Leyden, and the books of the guild also tell us that he remained a member in 1649 In 1650 he ceased to subscribe, and works bearing his name and the date of 1653 give countenance to the belief that he had then settled at Amsterdam, where he continued his studies under Rembrandt His companions at the time would naturally be De Hooch and Van der Meer, whose example he soon followed when it came to his turn to select the class of subjects for which his genius fitted him Under the influence of Rembrandt he produced the Woman Taken in Adultery, a large picture with the date of 1653, in the Louvre, in which no one would suspect the painter of high life or taverns were it not that his name is written at full length on the canvas The artist who thus repeated the gospel subjects familiar to

Flinck and Eeckhout was also acquainted with the Oriental wardrobe of Rembrandt, and ready to use it, like all his contemporaries. But he probably observed that sacred art was ill suited to his temper, or he found the field too strongly occupied, and happily for himself, as well as for his admirers, he turned to other subjects for which he was better fitted. We may doubt whether he tried the style of allegory as illustrated in a picture of Justice Protecting Virtue and Chastising Vice in the gallery of the Hague. There is every reason to think that this rough and frosty composition was wrought by quite another master. What Metsu undertook and carried out from the first with surprising success was the low life of the market and tavern, contrasted with wonderful versatility by incidents of high life and the drawing room. In each of these spheres he combined humour with expression, a keen appreciation of nature with feeling, and breadth with delicacy of touch, unsurpassed by any of his contemporaries. In no single instance do the artistic lessons of Rembrandt appear to have been lost upon him. The same principles of light and shade which had marked his school work in the Woman Taken in Adultery were applied to subjects of quite a different kind. A group in a drawing room, a series of groups in the market-place, a single figure in the gloom of a tavern or parlour, was treated with the utmost felicity by fit concentration and gradation of light; a warm flush of tone pervaded every part, and, with that, the study of texture in stuffs was carried as far as it had been by Terburg or Dow, if not with the finish or the *brio* of De Hooch. Metsu's pictures are all in such admirable keeping, and so warm and harmonious in his middle or so cool and harmonious in his closing time, that they always make a pleasing impression. They are more subtle in modulation than Dow's, more spirited and forcible in touch than Terburg's, and, if Terburg may of right claim to have first painted the true satin robe, he never painted it more softly or with more judgment as to colour than Metsu.

That Metsu married and became a citizen of Amsterdam in 1659 would only prove that his residence in the commercial capital of the Netherlands was later than historians have generally assumed. But there is no reason to think that Metsu claimed his citizenship at once. The privileges of a burgess were given in exchange for a payment of dues, and these painters had various ways of avoiding unless they married. One of the best pictures of Metsu's manhood is the Market place of Amsterdam, at the Louvre, respecting which it is difficult to distribute praise in fair proportions, so excellent are the various parts, the characteristic movement and action of the *dramatis personæ*, the selection of faces, the expression and the gesture, and the texture of the things depicted. A tin can in the arm of a cook is a marvel of imitation, but the cook's face is also a marvel of expression. Equally fine, though earlier, are the Sportsman (dated 1661) and the Tavern (also 1661) at the Hague and Dresden Museums, and the Game Dealer's Shop, also at Dresden, with the painter's signature and 1662.

Metsu is one of the painters of whose skill Holland still preserves examples, yet whose best pictures are either in England or in France or in the galleries of Germany. The value of his works is large, and at the Pommersfelden sale in 1867 the Jealous Husband Dictating his Wife's Letters though but one of several replicas was bought by Lord Hertford for little short of £2000 while for the Ride of the Prince of Orange in the Gsell collection at Vienna £3000 was paid by Baron Rothschild in 1873. (J. A. C.)

METTERNICH, Clemens Wenzeslaus, Prince (1773–1859), first minister of Austria from 1809 to 1848, was the son of a Rhenish nobleman employed in high office by the Austrian court. He was born at Coblentz in 1773. At the age of fifteen he entered the university of Strasburg. The French Revolution was then beginning. Everywhere the spirit of hope gave to men's language an exaltation and a confidence hardly known at any other epoch. But the darker reality soon came into view. Metternich was a witness of the riot in which the town hall of Strasburg was pillaged by a drunken mob; his tutor subsequently became a member of the revolutionary tribunal in Alsace. If we are to trust to Metternich's own account of the formation of his opinions, the hatred of innovation, which was the ruling principle of his later life, arose from his experience of the terrible results which followed at this time from the victory of so-called liberal ideas. But in reality Metternich was an aristocrat and a conservative by birth and nature. His sentiment in things political was that of a member of a refined and exclusive society which trusts to no intelligence but its own, and hardly sympathizes with larger interests. The aggressions and violence of the Revolution from 1789 to 1799 gave Metternich an historical basis for his political theories, but the instinctive preferences of his own mind were the same from first to last. He began life as a young man of fashion and gallantry. His marriage in 1795 with the Princess Kaunitz, a granddaughter of the famous minister, fixed him in the highest circle of Austrian nobility. His first contact with the great political world was at the congress of Rastadt in 1798, where, under the auspices of the victorious French republic, arrangements were made for compensating the German princes and nobles whose possessions on the left bank of the Rhine had been ceded to France by the peace of Campo Formio. Metternich was the accredited agent of a group of Westphalian nobles; his private letters give a vivid picture of the rough and uncourtly diplomatists who had succeeded to the polished servants of the old French monarchy. In 1801 Metternich was appointed Austrian ambassador at Dresden, and in 1803 he was promoted to Berlin; but he had hardly become as yet a prominent man in Europe. His stay at Berlin was the turning point of his life. The war of the third coalition was impending. Austria united with England and Russia against Napoleon, and the task of the youthful ambassador was to win over the court of Berlin to the cause of the allies. Metternich seems to have done all that it was possible for him to do; but Prussia persisted in its neutrality. The earnestness with which Metternich had worked against France did not prevent him from remaining on the friendliest terms with M. Laforest, the French ambassador at Berlin; and so agreeable an account of him was transmitted to Paris by his rival that, at the close of the conflict, Napoleon himself requested that Metternich might henceforward represent Austria at the Tuileries. Metternich was accordingly sent to Paris in 1806. This was the beginning of the period when Austria, humbled but not exhausted by the blow of Austerlitz and by the losses accompanying the peace of Pressburg, determined, under the leadership of Count Stadion, to prepare for another war on a greater scale. But the sudden overthrow of Prussia, and the alliance between France and Russia which was made at Tilsit in 1807, added immeasurably to the difficulties of the court of Vienna. It became clear that Napoleon was intending to dismember Turkey, and to gain for himself some part of the spoils of the Ottoman empire. Metternich's advice was that Austria should endeavour to detach the czar from the French alliance, and by this means frustrate the plan of partition; but, should Russia hold fast to Napoleon, that Austria itself should unite with the two aggressors, and secure its share of Turkey. Oriental affairs, however, fell into the background, and in the summer of 1808 Metternich was convinced that Napoleon was intending to attack Austria, though not immediately. He warmly supported Count Stadion's policy in raising the forces of Austria to the highest strength, and, although he did not share the minister's hopes in a general rising throughout Germany, he expressed in his despatches no distrust of the power of Austria to cope with Napoleon. This is the more singular because, after the disastrous issue of the campaign of 1809, Metternich seems to have taken credit for having opposed the policy of war. Napoleon again captured Vienna, the battle of Wagram was lost, and after a long negotiation Austria had to purchase peace by the cession of part of Austrian Poland and of its Illyrian provinces. Metternich, who had virtually taken Count Stadion's place immediately after the battle of Wagram was now installed as minister of foreign affairs. The first striking event that took place under his administration was the marriage of Marie Louise, daughter of the emperor Francis, to his conqueror Napoleon. To do justice to Metternich's policy it must be remembered that the alliance of Tilsit between France and Russia was still in existence, and that Austria was quite as much threatened by the czar's designs upon Turkey as by Napoleon's own aggressions. Metternich himself seems in spite of his denials to have been the real author of the family union between the houses of Hapsburg and Bonaparte,—a most politic, if not a high spirited measure, which guaranteed Austria against danger from the east, at the same time that it gave it at least some prospect of security from attack by Napoleon, and enabled Metternich to mature his plans for the contingency of an ultimate breach between France and Russia. In 1812 this event occurred. Metternich, in nominal alliance with Napoleon, sent a small army into southern Russia, allowing it to be understood by the czar that the attack was not serious. Then followed the annihilation of the French invaders. While Prussia, led by its patriots, declared war against Napoleon, Metternich, with rare and provoking coolness, held his hand, merely stating that Austria would no longer regard itself as a subordinate ally, but would act with all its force on one side or the other. The result of this reserve was that Metternich could impose what terms he pleased on Russia and Prussia as the price of his support. The armies of these two powers, advancing into central Germany, proved no match for the forces with which Napoleon took the field in the spring of 1813; and the hard fought battles of Lutzen and Bautzen resulted in the retreat of the allies. After the combatants had made an armistice, Metternich tendered Austria's armed mediation, requiring Prussia to content itself with the restoration of its territory east of the Elbe, and leaving Napoleon's ascendency in Germany almost untouched. Napoleon, after a celebrated interview with Metternich madly rejected terms so favourable that every Prussian writer has denounced Metternich's proposal of them as an act of bitter enmity to Prussia. On the night of the 10th of August the congress of Prague, at which Austria, as armed mediator, laid down conditions of peace, was dissolved. Metternich himself gave orders for the lighting of the watch fires which signalled to the armies in Silesia that Austria had declared war against Napoleon. The battle of Leipsic and the campaign of 1814 in France followed. Metternich steadily pursuing the policy of offering the most favourable terms possible to Napoleon, and retarding the advance of the allied armies upon the French capital. Metternich had nothing of that personal hatred towards the great conqueror which was dominant both in Prussia and in England; on the contrary, though he saw with perfect clearness that, until Napoleon's resources were much diminished no one could be safe in Europe, he held it possible to keep him in check without destroying him, and looked for the security of Austria in the establishment of a balance of power in which neither Russia nor France should preponderate, while Prussia should be strictly confined within its own limits in northern Germany. The assistance of the Austrian army, which was no doubt necessary to the allies, had, so far as related to Prussia, been dearly purchased. When, at the beginning of 1813, Prussia struck for the freedom of Germany, its leading statesmen and patriots had hoped that the result of the war of liberation would be the establishment of German unity, and that the minor German princes, who had been Napoleon's vassals since 1806, would be forced to surrender part of their rights as sovereigns, and submit to a central authority. This dream, however, vanished as soon as Austria entered the field as an ally. It was no part of Metternich's policy to allow anything so revolutionary as German unity to be established, least of all under the influence of Prussian innovators. He made treaties with the king of Bavaria and Napoleon's other German vassals, guaranteeing them, in return for their support against France, separate independence and sovereignty when Germany should be reconstructed. Accordingly, though the war resulted, through Napoleon's obstinate refusal of the terms successively offered to him, in the limitation of France to its earlier boundaries and in a large extension of Prussia's territory, the settlement of Germany outside Prussia proceeded upon the lines laid down by Metternich, and the hopes of unity raised in 1813 were disappointed. A German confederation was formed, in which the minor sovereigns retained supreme power within their own states, while the central authority, the federal diet, represented, not the German nation, but the host of governments under which the nation was divided. Metternich even advised the emperor Francis of Austria to decline the old title of German emperor, disliking any open embodiment of the idea of German unity, and preferring to maintain the ascendency of Austria by a gentle pressure at the minor courts rather than by the avowed exercise of imperial rights. In this unprogressive German policy Metternich was completely successful. His great opponent, Stein, the champion of German unity and of constitutional systems, abandoned his work in despair, and refused the useless post of president of the diet, which Metternich, with a kind of gentle irony, offered to him.

The second branch of Metternich's policy in 1813–14 was that which related to Italy. Following the old maxims of Austrian statesmanship, Metternich aimed not only at securing a large territory beyond the Alps but at making the influence of Austria predominant throughout the Italian peninsula. The promises of national independence which had been made to the Italians when they were called upon to rise against Napoleon were disregarded. In the secret clauses of the first treaty of Paris the annexation of both Lombardy and Venetia was guaranteed to Austria, and the rest of Italy was divided into small states as of old. Napoleon's return from Elba led to the downfall of Murat, who had been allowed to retain the kingdom of Naples, and to the reunion of this country with Sicily, under the Bourbon Ferdinand. After the second overthrow of Napoleon, Metternich endeavoured to make every Italian sovereign enter into a league under Austria's presidency. Ferdinand of Naples accepted the position of vassal, but the pope and the king of Sardinia successfully maintained their independence. With the construction of the German federation, and the partial construction of an Italian federation, both under Austria's guidance, the first part of Metternich's career closes. He had guarded Austria's interests with great skill during the crisis of 1813 and 1814. It was not his own fault, but the fault of ages, that Austria's interests were in antagonism to those of German and of Italian nationality. He thought as an Austrian, and as nothing else; his task was to serve the house of Hapsburg, and this he did with signal ability and success. To denounce Metternich as a kind of criminal, according to the practice of Prussian writers, because he did not work for German unity, is to ignore the existence of such a thing as state-policy. Judged by the ordinary standards of practical statesmanship, not by the philosophy of history, Metternich's action in 1813 and 1814 was that of a very superior man, and the qualities of calmness and dexterity which he displayed would have given an infinitely greater effectiveness to the life of his great rival Stein, who in patriotic and moral enthusiasm was so far above him.

The second part of Metternich's career, which extends from 1815 to 1848, is that of a leader of European conservatism. It is difficult to describe his attitude towards almost all the great questions which were now arising as any but one of absolute blindness and infatuation. He acknowledged that exceptional circumstances in the past had made it possible for England to exist under a constitution, he knew that France would not surrender the *Charta* given to it by King Louis XVIII, but in all other great states he maintained that there were no alternatives but absolute monarchical government and moral anarchy. His denunciations of liberals and reformers everywhere and at all times are perfectly childish, and in many instances his hatred of change led him into errors of judgment not surpassed in the annals of political folly. When Napoleon fell, there was a prospect of the introduction of constitutional government throughout a great part of Europe. King Frederick William, stimulating the efforts of the Prussian people against France by the hopes of liberty had definitely promised them a constitution and a general assembly. The czar had determined to introduce parliamentary life into the kingdom of Poland, and even hoped to extend it after some interval, to Russia. The Federal Act drawn up for Germany at the congress of Vienna declared that in every state within the German league a constitution should be established. Against this liberal movement of the age Metternich resolutely set his face. Though wide general causes were at work, the personal influence of the Austrian statesman had no small share in prolonging the existence of autocratic government, and in developing that antagonism between the peoples and their rulers which culminated in the revolutions of 1848. The nature of the Austrian state, composed of so many heterogeneous provinces and nationalities, no doubt made it natural for its representative to defend and exalt the principle of personal sovereignty, on which alone the unity of Austria was based, the relation of Austria to Italy rendered the growth of the sentiment of nationality a real source of danger to the house of Hapsburg, but Metternich's abhorrence of constitutional and popular ideas was more than the outcome of a calculating policy. He was not a man of much faith, but one belief he held with all the force of religious conviction,—namely the belief that his own task and mission in the world was to uphold established authority. All efforts to alter the form or to broaden the basis of government he classed under the same head, as works of the spirit of revolution, and in one of his most earnest writings he places side by side, as instances of evil sought for its own sake, the action of the secret societies in Germany, the Carbonaria of Italy, and the attempts of the English to carry the Reform Bill. Working on principles like these, and without the shadow of a doubt in his own wisdom, Metternich naturally proved a great power at a time when the sovereigns who had inclined to constitutional ideas began to feel the difficulties in the way of putting them into practice. Metternich's advice, tendered with every grace of manner and with the most winning and persuasive art, was indeed not hard for rulers to accept, for he simply recommended them to give up nothing that they had got. It was at the congress of Aix-la-Chapelle (1818) that the retrograde tendency, which was now succeeding to the hopes of 1815, first gained expression. An agitation among the students at the German universities had caused some scandal in the previous year, and secret societies had just been discovered in Russia. Metternich plied the king of Prussia with arguments for withholding the national representation which he had promised to his people, and stimulated the misgivings which were arising in the mind of the czar, hitherto the champion of European liberalism. A few months later the murder of Alexander's German agent, Kotzebue, by a fanatical student gave Metternich an excellent pretext for organizing a crusade against German liberty. A conference of ministers was held at Carlsbad. The king of Prussia allowed his representative to follow Metternich's lead. The resistance of the constitutional minor states proved of no avail, and a series of resolutions was passed which made an end of the freedom of the press throughout Germany, and subjected the teaching and the discipline of the universities to officers of state. A commission was established at Mainz to investigate the conspiracies which Metternich alleged to have been formed for the overthrow of all existing governments, and for the creation of a German republic, one and indivisible. In the following year new articles were added by Metternich's direction to the original Federal Act, the most important being one that forbade the creation in any German state of an assembly representing the community at large, and enforced the system of representation by separate estates or orders, each possessed of certain limited definite rights and all alike subordinate to the supremacy of the crown. Metternich would gladly have made an end of the parliamentary constitutions which had already come into being in Bavaria and the southern states but he was unable to attack them openly, and had to confine himself to the advocacy of strict monarchical principles through his representatives at these courts. With regard to Prussia, however, he was completely successful. The king of Prussia broke his promise of establishing a national representation, and satisfied his conscience by creating certain powerless provincial diets, exactly as Metternich had recommended him. Throughout Germany at large a system of repression was carried out against the advocates of constitutional right. The press was silenced, societies were dissolved, prosecutions became more and more common. While Metternich imagined himself to be stifling the spirit of discontent, he was in fact driving it into more secret and more violent courses, and convincing eager men that the regeneration of Germany must be sought not in the reform but in the overthrow of governments.

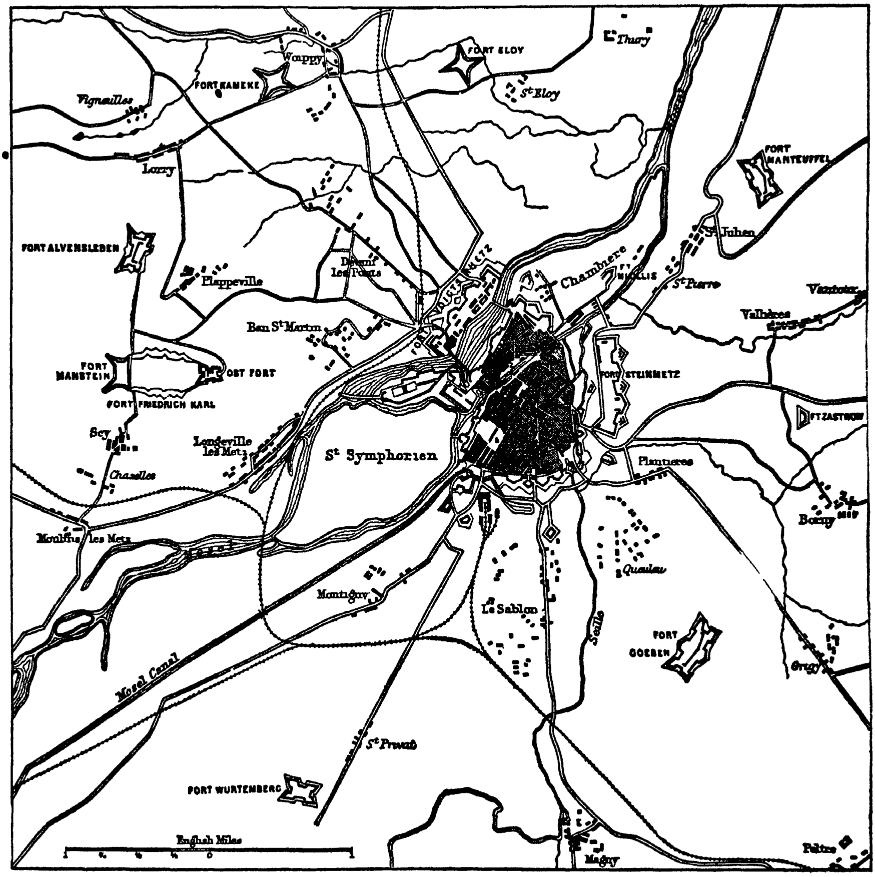
Meanwhile revolution broke out in Spain and Italy. Ferdinand of Spain, who had restored despotism, was compelled, in March 1820, to accept the constitution of 1812 which he had subverted. The same constitution was accepted a few months later by Ferdinand of Naples. Spain was outside Metternich's range, but his hand fell heavily upon Naples. A congress of the great powers was held at Troppau in October 1820. Metternich, who was president, as he had been at Vienna, and continued to be in later congresses, completely won over the czar to his own views. Resolutions in favour of an intervention, if necessary by force of arms, against the Neapolitan liberal Government were adopted by Austria, Russia, and Prussia, though England and France held aloof. The congress was then adjourned to Laibach in Carniola, whither Ferdinand of Naples was summoned, in order that he might mediate between the powers and his people, and induce the latter to give up a constitution which offended the three northern courts. Ferdinand's journey and mediation were an imposture as regarded the Neapolitans, he pretended that he went to negotiate on behalf of his people, when in fact his intention was exactly the same as Metternich's, namely, to have absolute monarchy restored. The proceedings of the congress at Laibach were a farce. A letter was concocted by Metternich for King Ferdinand to send to his subjects, informing them that the powers would not permit the constitution to exist, and that, in default of their submission, the allied courts would employ force. The British Government, while protesting against the joint action of the three powers as an assumption of international sovereignty, was perfectly willing that Austria, as a state endangered by the Neapolitan revolution, should act on its own account. Metternich, however, continued to treat the Neapolitan question as the affair of Europe, and maintained his concert with Russia and Prussia. Early in 1821 an Austrian force acting in the name of the allies, entered central Italy. The armies opposed to it collapsed, and the Austrians entered Naples on March 24. But in the meantime a revolution broke out in Piedmont, which threatened to cut off the Austrians from their supports, and to raise all Italy against them. For a moment the bold action of Metternich seemed to have resulted in immense danger both to his own conservative policy and to the peace of Europe for it was believed that the Piedmontese revolution would be answered, not only by a general Italian movement, but by a rising against the Bourbons in France. The cloud, however, passed away. Order was quickly restored in Piedmont, Lombardy was safely held by Austrian garrisons, and the conclusion of the Italian difficulties, in which Metternich had played a very difficult part with great resolution and dexterity, was his complete and brilliant personal triumph. No statesman in Europe at this moment held a position that could compare with his own.

At the congress of Verona, held in 1822, the affairs of Spain were considered by the powers. In the end, the Spanish constitution was overthrown by a French invading army, but, though the arm employed was that of France, the principle of absolutism which animated the crusade was that which Metternich had made his own. A severe check, however, now met him in another quarter. Greece had risen against Turkish rule in 1821. The movement was essentially a national and a religious one, but Metternich treated it as a Jacobinical revolt against lawful authority, —confusing, or affecting to confuse, the struggle for national independence with the shallow and abortive efforts of political liberalism in Italy and Spain. Metternich's attitude towards the Greeks was for some time one of unqualified hostility. If, under the pressure of the Tilsit alliance, he had once been willing that Austria should join Russia in dismembering Turkey, he had now reverted to the principle of maintaining Turkey at all costs against a Russian advance southwards, and he attributed the Greek movement to the efforts of Russian agitators unauthorized by the czar. His desire was that the sultan should deprive Russia of all possible cause for complaint as regarded its own separate interests, and so gain freedom to deal summarily with the Greeks. Metternich's hopes failed, partly through the obstinacy of the Turks, partly through the wavering conduct of Alexander, and partly through the death of Castlereagh and the accession of Canning to power. It was in great part owing to Canning's moral support that Greece ultimately became an independent state, and the extraordinary violence of Metternich's language whenever he mentions this English statesman marks only too well the opposite character of his aims. No politician has left a more damning record against himself than Metternich in his bigoted abuse of Canning. The Greek question, however, was only the first on which the judgment of events was now beginning to declare itself against Metternich and all his principles. The French revolution of 1830 shattered the moral fabric which he had so proudly inaugurated, and in great part himself raised, in 1815. The accord that grew up between England and France now made any revival of the kind of presidency that he had once held in Europe impossible. He was indeed bold and rapid in throwing troops into the papal territory when revolutionary movements broke out there in 1831 and 1832, though war with France seemed likely to result from this step. He was as unsparing as he had been in 1819 in suppressing the agitation which after 1830 spread from France to Germany; and the union of the three eastern courts was once more exhibited in the meeting of the monarchs which took place at Munchengratz in 1833, and in a declaration delivered at Paris, insisting on their right of intervention against revolution in other countries. It was, however, the new czar of Russia, Nicholas, who was now the real head of European conservatism, and the stubborn character, the narrow, unimaginative mind, of this prince made it impossible for Metternich to shape his purposes by that delicate touch which had been so effective with his predecessor. But in Austria itself Metternich continued without a rival. In 1835 the emperor Francis, with whom he had worked for nearly thirty years, died. Metternich, himself falling into the mental habits of old age, remained at the head of the state till 1848. The revolution of that year ended his political career. He resigned office with the dignity of demeanour which had never failed him, his life was scarcely safe in Vienna, and the old man came for a while to England, which he had not visited since 1794. Living on till June 1859, he saw every great figure of his earlier life, and many that had appeared on the horizon since his own prime, pass away, and a few more months of life would have enabled him to see the end of that political order which it had been his life-work to uphold, for the army of Napoleon III. was crossing the Sardinian frontier at the moment when he died, and before a second summer had gone Victor Emmanuel had been proclaimed king of Italy.

Metternich was a diplomatist rather than a statesman. His influence was that of an expert manager of individuals, not of a man of great ideas. All his greatest work was done before fifty, and at an age when most statesmen are in the maturity of their powers he had become tedious and pedantic. His private character was very lovable. He was an affectionate if not a faithful husband, a delightful friend, and a most tender father. The excessive egotism which runs through his writings gives perhaps an impression of weakness which did not really belong to his nature. Drawn by a firmer pen, the scene in which he describes himself labouring in the German conferences of 1820, while his favourite daughter was dying in an adjoining room, would have been one of the most affecting things in political biography. The man who could so have worked and felt together must have possessed no ordinary strength of character, no common force of self-control.

The collection of Metternich's writings published by his family under the title of *Denkwurdigkeiten*, along with French and English editions, contains letters and despatches of great value. The autobiography is not always trustworthy, and must be read with caution. Gentz's correspondence is of first rate importance for the years 1813–30. Original papers are also contained in various German works upon particular events or movements, as in Oncken for the negotiations of 1813; Welcker Aegidi, Nauwerck for German affairs in 1819 and following years, Prokesch von Osten for Eastern affairs. (C. A. F.)

METZ, the capital of German Lorraine, and one of the strongest fortresses in Europe, is situated at the confluence of the Moselle and the Seille, 80 miles to the north-west of Strasburg, and 190 miles to the east of Paris. It is the seat of a military governor, the judicial and administrative authorities of Lorraine, a Roman Catholic bishop, Protestant and Jewish consistories, and a chamber of commerce. The general appearance of the town is quaint and irregular, but there are also many handsome modern streets. The Moselle flows through it in several arms, crossed by fourteen or fifteen bridges. In the south-west corner of the town is the esplanade, an extensive open space commanding a fine view of the fertile "Pays Messin" around Metz. The most interesting of the ten city gates is the Porte d'Allemagne or Deutsches Thor, a castellated structure erected in 1445, and still bearing traces of the siege of Charles V. Metz contains seven Roman Catholic churches, two Protestant churches, and a synagogue. The cathedral, with huge pointed windows, slender columns, and numerous flying buttresses, was begun in the 13th century, and finished in 1546, and belongs to the decadence of the Gothic style. The Gothic churches of St Vincent and St Eucharius, and the handsome garrison church, completed in 1881, also deserve mention. Among secular buildings the most important are the large covered market, the town hall, the palace of justice, the theatre, the governor's house, and the various buildings for military purposes. The public library contains 35,000 volumes, including an extensive collection of works relating to the history of Lorraine. In the same building is the museum, which contains a picture gallery, a numismatic cabinet, and a collection of specimens of natural history. Metz also possesses several learned societies and charitable institutions, a gymnasium, three seminaries, and a military academy. The cemetery of Chambière contains the graves of 8400 French soldiers who died here in 1870.



Metz and Neighbourhood

1 Palace of Justice 2 Prefecture 3 Cathedral 4 Town Hall and Governor's House

The commerce and industry of Metz have not yet entirely recovered from the blow inflicted by the withdrawal of French capital in 1871. The principal articles of manufacture are leather, coarse cloth and canvas, gunpowder, arms, needles, billiard tables, hats, and artificial flowers. There are several large iron works in the neighbourhood. The trade of Metz is chiefly carried on in leather, timber, wine, brandy, liqueurs, beer, preserved fruits, and hardwares. A large annual fair is held here. The civil population of Metz, which in 1869 amounted to 48,066, sank in 1872 to 33,134. Since then it has steadily increased, and in 1881 was 43,275, about half of whom were Germans. The garrison of Metz consists of 10,000 men, or including the surrounding forts nearly 16,000. The total of 58,813 includes 17,000 Protestants and 1600 Jews.

History —Metz, the Gallic Divodurum, was the chief town of the Mediomatrici, and was also called by the Romans Mediomatrica, a name from which the present form has been derived by contraction Cæsar describes it as one of the oldest and most important towns in Gaul The Romans recognizing its strategical importance, fortified it and supplied it with water by an imposing aqueduct, the remains of which still exist Under the Roman emperors Metz was connected by military roads with Toul, Langres Lyons, Strasburg, Verdun Rheims and Treves Christianity was introduced in the 3d century of our era In the middle of the 5th century the town was plundered by the Huns under Attila subsequently it came into the possession of the Franks and in 512 it was made the capital of Austrasia On the partition of the Carolingian realms in 843 Metz fell to the share of the western kingdom as the capital of Lorraine Its bishops whose creation reaches back to the 4th century, now began to be very powerful Metz acquired the privileges of a free imperial town in the 12th century and attained great commercial prosperity In 1552 it fell into the hands of the French through treachery and was heroically and successfully defended against Charles V by the young duke of Guise It now sank to the level of a French provincial town and its population dwindled from 60 000 to 22 000 (1698) At the peace of Westphalia Metz with Toul and Verdun, was formally ceded to France in whose possession it remained for upwards of two centuries In August 1870 the successes of the German troops compelled Marshal Bazaine and the French army of the Rhine to seek shelter behind the fortifications of Metz which was forthwith subjected by the Germans to a rigorous blockade After an investment of ten weeks during which not a single shot was fired at the town Bazaine capitulated surrendering to the victors an army of nearly 180 000 men several hundred cannon and an immense quantity of military stores of all kinds By the peace of Frankfort in 1871 Metz was again united to the German empire Marshal Fabert and Generals Custine and Kellermann were natives of Metz

As a fortress Metz has always been of the highest importance and it now ranks with Strasburg as one of the two great bulwarks of the west frontier of Germany The original town walls were replaced by ramparts in 1550 and the citadel was built in 1566 In 1674 the works were reconstructed by the celebrated military engineer Vauban Under Napoleon III the fortress was strengthened to meet the demands of modern warfare and since 1871 the Germans have spared neither time nor money in completing and supplementing his plans The present fortifications of Metz consist of two lines—an inner circle of bastions and ramparts enclosing the city itself and an outer circle of large detached forts on the surrounding hills The inner line is strengthened by two citadels one of which is advanced as a tete de pont on the left bank of the Moselle The outer circle consists of nine or ten large forts, connected with each other by smaller fortifications and commanding all the approaches to the city They form a large fortified camp with a circumference of 15 miles within which are twelve villages and numerous country houses and farms The most distant of the outlying forts is about 3½ miles from the cathedral Their names and positions may be seen on the annexed plan Previous to 1870 the fortress of Metz had never succumbed to an enemy

Sources of Information —Westphal *Geschichte der Stadt Metz* 1875 78 Georg Lang *Metz und seine Umgebungen* 1883 and *Statistisch topographisches Handbuch fur Lothringen* The official German account of the blockade of Metz in 1870 will be found in the history of the Franco German war issued by the general staff at Berlin 1872 *sq* A succinct account is given by Georg Lang *Die Kriegs operationen um Metz im Jahr* 1870 2d ed Metz 1880

MEULEN, Antony Francis van der (1634–1690), was called to Paris about 1666 by Colbert, at the instance of Le Brun, to fill the post of battle painter to Louis XIV Born in 1634 at Brussels, he had at an early age eclipsed his master Peter Snayers, and the works executed by him for the king of France during the campaigns of Flanders (1667) so delighted Louis that from that date Van der Meulen was ordered to accompany him in all his expeditions In 1673 he was received into the French Academy, and attained the grade of councillor in 1681 Lodged in the Gobelins, richly pensioned, and loaded with honours, he died at Paris in 1690 Detached works from his hand are to be seen in various collections, but he is best represented by the series of twenty three paintings, mostly executed for Louis XIV, now in the Louvre They show that he always retained his Flemish predilections in point of colour, although in other respects his style was modified by that of the French school

See *Mém inédit Acad de Peinture*, 1854 , Descamps, *Vies des Peintres Flamands*

MEURTHE-ET MOSELLE, a department in the north east of France, formed in 1871 out of those parts of the old departments of Meurthe and Moselle which continued French, and deriving its name from the two principal rivers which water it Prior to 1790 it belonged to ancient Lorraine, or to one or other of the bishoprics of Toul, Metz, and Verdun It lies between 5° 25 and 7° 5 E long and 48° 25 and 49° 5 N lat, and is bounded on the E by Alsace-Lorraine, on the N by Belgium and the grand-duchy of Luxemburg, on the W by the department of Meuse, and on the S by that of Vosges The superficial area is 2020 square miles Geologically Meurthe-et-Moselle has five well marked regions following each other in regular succession from east to north west On the frontier of Alsace are the Vosges mountains, of Trias sandstone (*gres Vosgiens*), with a maximum elevation of 3000 feet A narrow band of variegated sandstone divides the Vosges from the second region, formed of shelly limestone, which extends as far as the Meurthe on the north and the Moselle on the west The third region is formed by the variegated marls which cover the rich saline strata of the neighbourhood of Nancy The Jura limestones of the Lias and Oolite, to the north west and west of the department, form the last two regions Here there is a maximum elevation of 1400 feet, and the plateau of Briey stretches out towards that of the Ardennes Between the Vosges and the Ardennes the valley of the Moselle runs from south to north, forming the main artery of the department, the lowest level (570 feet) occurs where the river leaves it Only a small part of the drainage of Meurthe et Moselle flows into the Meuse The Moselle runs north west from its entrance into the department as far as Toul, north east from Toul to Frouard, where it receives its principal affluent, the Meurthe, and becomes navigable, north from Frouard to Pagny sur Moselle, passing to Pont à Mousson The principal affluents of the Moselle are the Madon and the Orne on the left, and on the right, besides the Meurthe, the Seille, which in one part of its course forms the boundary of Alsace Lorraine The Meurthe, which flows to the north west from Raon l Étape to Frouard, passes on to Baccarat, Lunéville, St Nicholas, and Nancy, and is swelled on the right by the Vezouse and the Sanon, and on the left by the Mortagne The principal tributary of the Meuse within the department is the Chiers, which takes its course by Longwy and Longuyon Climatologically Meurthe et Moselle belongs to the Vosgian region Its mean annual temperature is 52° Fahr, being 2° Fahr lower than that of Paris (which has the same latitude) The thermometer in severe winters falls to 13° Fahr, while in summer it reaches 100° Fahr This is to be accounted for by the general elevation of the department, the proximity of the mountains, the arrangement of the valleys (which lie open towards the north), and the distance from the sea

More than half of the department consists of culturable land, one-fourth of forests, and one tenth of meadow land In 1878 there were 54,346 horses, more than 100,000 sheep, 85,000 pigs, 74,000 cattle, 15 000 goats 21,000 dogs and 17,000 hives of bees The crops for the same year amounted to 454,192 quarters of wheat, 37 500 quarters of barley, 35 078 quarters of rye 570,884 quarters of oats, 9 079,125 bushels of potatoes, and 76,868 tons of beet root Hops, tobacco, colza, hemp and flax also occupy a considerable area The annual yield of the vineyards (56 square miles in extent) exceeds £900 000, the wines of Toul are the best The most common fruit trees are the pear the apple, the walnut the cherry, and the plum Of forest trees the oak and the wych elm are most frequent in the west of the department the beech and the fir in the Vosges The French school of forestry has its seat at Nancy The metallurgic industry is highly developed, and has made very rapid progress within the last few years Even in 1872 there was a consumption of 350 000 tons of coal four fifths of which came from Saarbruck and the remaining fifth from Belgium. In 1877 the iron ore obtained amounted to 1,000,000 tons, of which two thirds came from the beds near Nancy, the remainder from the neighbourhood of Longwy In 1880 the department produced a third of the pig iron made in France (more than 500,000 tons).

In 1877 the yield was 43,000 tons. Besides blast furnaces, forges, and rolling-mills, there are manufactories of files and boring tools, agricultural implements, and furniture In the production of salt the department holds the first rank in France, the salt bearing tracts cover more than 150 square miles, the beds having a mean thickness of 65 feet The principal salt working centres (St Nicolas, Varangeville, and Rosières aux Salines) lie between Nancy and Lunéville, the annual value of rock-salt and refined salt produced exceeds £500,000, subsidiary to this production is an important manufacture of soda salts The other chemical products are prussiate of potash, bone black, wax candles, soap, and matches Stone quarrying and the manufacture of plaster and lime are also important branches of industry The flint glass manufactory of Baccarat, which employs nearly 1500 workmen, is well known, that of plate glass at Cirey (with 1000 workmen) produces plates of great size The faience manufactories of Luneville, Toul, and Longwy are important Mention may also be made of the manufacture of window glass, watch glasses, and drinking glasses The tobacco manufacture at Nancy employs 1000 workmen, tanning, glove making, hat making, in felt and straw, wool spinning, and the manufacture of army clothing are also carried on Nancy is renowned for its embroidery, which is, however, diminishing in importance It also possesses factories for cotton spinning and cotton stuffs, and for hosiery The starch manufactories and the breweries, especially that of Tantonville, the largest in France, are highly productive Nancy also carries on distilleries, grain mills, paper mills, manufactories of pasteboard objects, and a large printing establishment The commerce of the department is effectively served by 300 miles of railway (the principal line being that from Paris to Strasburg through Nancy), by a number of good roads, and by several navigable rivers and canals The main waterway is formed by the canal between the Marne and the Rhine which runs by Toul and Nancy, and traverses the department from west to east This canal communicates with the Moselle which is navigable from Frouard downwards and with the new eastern canal which reascends the Moselle as far as Épinal, and which is intended to unite the Meuse and the Moselle with the Saône and the Rhone The population of Meurthe et Moselle in 1881 was 419,317 inhabitants It constitutes the diocese of Nancy has its court of appeal at Nancy, and forms a part of the district of the 6th army corps (Chalons sur Marne) There are 4 arrondissements (Nancy, Briey, Lunéville, and Toul), 29 cantons, and 597 communes The capital is Nancy, and the other principal towns are Pont a Mousson, formerly the seat of a university Longwy (5064) a fortified place, and Baccarat (6013), celebrated for its glass works

MEUSE, MAESE, or MAAS, a river of France, Belgium, and Holland, discharging into the North Sea or German Ocean, has a course (variously measured) of some 500 or 550 miles, about 300 miles lying within France Rising in the department of Haute Marne (1342 feet), at a point where the plateau of Langres borders on the Monts Faucilles, it follows a winding course, first from south to north, then to north west, and afterwards to north, across the departments of Vosges, Meuse, and Ardennes, passing by Neufchateau, Vaucouleurs, Commercy, St Mihiel, Verdun, Sedan, Mézières, and Givet Naturally navigable below Verdun, it has been made so from Troussey, where it meets the canal which unites the Marne to the Rhine, and from this point to Liége it admits vessels of from 6 to 7 feet draught After traversing a wide valley covered by green meadows, the Meuse, below Mézières, flows through narrow gorges confined between rocky walls 200 or 300 feet high, formed by the plateau of the Ardennes The hills of the Argonne, by which it is hemmed in on its upper course, prevent its receiving any important affluent before the Chiers and the Semoy, which both fall into it on the right in the Ardennes At the point where it leaves France its ordinary volume is about 1000 cubic feet In Belgium it runs picturesquely between the districts of Famenne and Condroz on the right, and those of Les Fagnes and Hesbaye on the left Above Dinant it receives the Lesse, whose valley is celebrated for its wonderful grottoes, and at the foot of the citadel of Namur it is joined on the left by its principal affluent, the Sambre, whose north easterly direction it takes It then takes its course through the busy valley in which Huy, Seraing, and Liége are situated, receiving the Ourthe on its right Resuming a northerly direction, then taking one to the north-west, and finally one to the west, the Meuse passes in front of the Dutch citadel of Maestricht to Roermonde, so called from its confluence there with the Roer, and to Venlo, where the canal between the Meuse and the Scheldt begins Flowing thence through an absolutely unbroken plain, it finally joins the Rhine, to which it gives its own name, although the volume of its waters is twenty times less than that of the German river. It is at Gorcum that the Waal, the first separate arm of the Rhine, brings to the Meuse two-thirds of the waters of that river The Meuse soon after divides into two branches While the Merwede flows due west, the southern arm falls into the Biesbosch, an estuary of the sea, formed four hundred and fifty years ago by an irruption of the sea over a country then cultivated and thickly peopled, and now the subject of attempts at reclamation On reaching Dordrecht, where the river navigation and sea navigation meet, and where the rafts which come down from the Black Forest are broken up, the Meuse again divides into two arms The Old Meuse flows due west, while the northern arm joins the Lek, a second branch of the Rhine, and continues its course to Rotterdam This is the most important branch of the estuary of the Meuse, and efforts are being made to regulate and deepen its channel by constructing one of those grand canals in which the Dutch are so skilful Schiedam and Vlardingen, both on the right, are the last places of importance on the banks of the river

MEUSE, a department in the north east of France, formed out of a part of Lorraine and portions of the Three Bishoprics, the Clermontais, and Champagne, derives its name from the river by which it is traversed from south to north It lies between 4° 52 and 5° 50 E long, and between 48° 25 and 49° 38 N lat, and is bounded on the N by Belgium and the department of Ardennes, on the E by that of Meurthe-et-Moselle, on the S by those of Vosges and Haute Marne, and on the W by those of Marne and Ardennes Of its superficial area (2405 square miles), about one-half belongs to the basin of the Meuse, which is enclosed to the east and west by the eastern and western Argonnes On the north-east it is watered by the Orne, a tributary of the Moselle, and the Chiers, which runs by Montmédy, and joins the Meuse a little beyond the northern limit of the department The other half sends its waters to the Seine through the Aire, a tributary of the Aisne, both of which take their rise here, and by the Ornain, an affluent of the Saux, these two last being tributary to the Marne The Meuse receives no important river in its course through this department The highest elevation (1388 feet) occurs to the south-west, on the line of the ridge which separates the basin of the Meuse from that of the Seine The heights gradually sink from south to north, but seldom fall below 1000 feet The hills of the western Argonne similarly sink rapidly down to the valley of the Saux, where the lowest level of the department (377 feet) is reached The climate of Meuse is transitional between the region of the Seine and that of the Vosges, its winters are less severe than those of the latter, but it is not so temperate as the former The mean annual temperature is 52° Fahr As at Paris, the maximum cold is 9° Fahr, the greatest heat rarely exceeds 95° Fahr

More than half the surface of the department consists of culturable lands, one fourth of forest, one tenth of meadow land The proportion of horses is larger than in any other French department, except La Manche There are 53,800 horses, 90,000 cattle, 145,000 sheep, 125,000 pigs, and nearly 30 000 beehives Cereals, potatoes, and beet root are the chief crops (in 1877 465,966 quarters of wheat, 104,660 quarters of barley, 585 355 quarters of oats, 7,677,374 bushels of potatoes, besides pulse, hemp, and colza) The vineyards produced more than 6,600,000 gallons of wine of good quality The forests, which are principally of oak, are rich in game, as are the rivers in fish The mineral wealth of the department includes iron ore, good freestone, and fossil phosphates of lime There are blast furnaces, iron copper, and bell foundries, wire-works, and manufactories of files hardware, and edge tools The cotton-spinning factories employ 15 000 spindles and 32,000 frames the woollen manufacture employs 5000 spindles, and some hundreds of persons are employed in the spinning and weaving of hemp, flax, and jute The glass works (particularly the manufactory of painted window glass transferred after the war of 1870 from Metz to Bar le Duc), paper mills, saw mills and flour mills, as well as the manufactures of lime, tiles and fire bricks, are worthy of mention Hosiery and embroidery also give occupation to a great number of workshops and the department is celebrated for its confectionery Meuse contains more than 300 miles of railway,—the principal lines being that from Paris to Strasburg through Bar le Duc and Commercy, that from Paris to Metz through Verdun, and the branch line to the Meuse The chief waterways are the canal connecting the Marne with the Rhine, and the canal of the Meuse, the two together have a length of 146 miles The population of the department in 1881 was 289,861,—a small number in proportion to its extent, and with a tendency to decrease Ecclesiastically it forms the diocese of Verdun, it has its court of appeal at Nancy, and constitutes part of the district of the army corps of Châlons-sur Marne There are 4 arrondissements,—Bar le Duc, Commercy, Montmedy, and Verdun,—28 cantons and 586 communes Bar-le Duc (population in 1881, 17 485) is the capital, Commercy has 5260 inhabitants and Montmédy 3000, St Mihiel (5915), on the Meuse, has good churches and some remarkable rocks, and is the seat of the departmental assize court

MEXICO

I ANCIENT MEXICO

THE name Mexico is connected with the name of the group of American tribes calling themselves *Mexica* (sing *Mexicatl*), or *Azteca* The word is related to or derived from the name of the Mexican national war god Mexitl, better known as Huitzilopochtli The Aztecs from the 12th century appear to have migrated from place to place over the mountain walled plateau of *Anahuac*, the country "by the water, so called from its salt lagoons, and which is now known as the valley of Mexico About 1325 they founded on the lake of Tezcuco the permanent settlement of Mexico Tenochtitlan, which is still represented by the capital city Mexico The name Mexico was given by the Spanish conquerors to the group of countries over which the Aztec power more or less prevailed at the time of the European invasion Clavigero (*Storia Antica del Messico*, vol i) gives a map of the so-called "Mexican empire," which may be roughly described as reaching from the present Zacatecas to beyond Guatemala, it is noticeable that both these names are of Mexican origin, derived respectively from words for "straw' and "wood" Eventually Mexico and New Mexico came to designate the still vaster region of Spanish North America, which (till cut down by changes which have limited the modern republic of Mexico) reached as far as the Isthmus of Panama on the south and took in California and Texas on the north Mexico in this wide sense is of high interest to the anthropologist, from the several native American civilizations which appear within its limits, and which conveniently if loosely group themselves round two centres, the Mexican proper and the Central American

When early in the 16th century the Spaniards found their way from the West India Islands to this part of the mainland of America, they came in view of nations cultured high above the level they had hitherto met with in the New World Here were not rude and simple tribes like the islanders of the Antilles, but nations with organized armies, official administrators, courts of justice, high agriculture and mechanical arts, and, what struck the white men especially, stone buildings whose architecture and sculpture were often of dimensions and elaborateness to astonish the builders and sculptors of Europe How a population of millions could inhabit a world whose very existence had been till then unknown to geographers and historians, and how its nations could have reached so high a grade of barbaric industry and grandeur, was a problem which naturally excited the liveliest curiosity of scholars, and gave rise to a whole literature Hernandez and Acosta shared the opinion of their time that the great fossil bones found in Mexico were remains of giants, and it was argued that, as before the deluge there were giants on the earth, therefore Mexico was peopled from the Old World in antediluvian times On the other hand the multitude of native American languages suggested that the migration to America took place after the building of the tower of Babel, and Siguenza arrived at the curiously definite result that the Mexicans were descended from Naphtuhim, son of Mizraim and grandson of Noah, who left Egypt for Mexico shortly after the confusion of tongues Although such speculations have fallen out of date, it is to be remembered in their favour that they were stepping stones to more valid argument, especially they induced the collection of native traditions and invaluable records of races, languages, and customs, which otherwise would have been lost for ever Even in the present century Lord Kingsborough was led to spend a fortune in printing a magnificent compilation of Mexican picture writings and documents in his *Antiquities of Mexico* by his zeal to prove the theory advocated by Garcia a century earlier, that the Mexicans were the lost tribes of Israel

Real information as to the nations of Mexico before Spanish times is very imperfect, but not altogether wanting It is derived partly from inspection of the natives themselves, their languages and customs, which may be now briefly considered, before going on to the recollections handed down in the native picture writings and oral traditions The remarks made by the accurate and experienced observer Alexander von Humboldt, who had seen more American tribes than almost any traveller, are still entitled to the greatest weight He considered the native Americans of both continents to be substantially similar in race characters Such a generalization will become sounder if, as is now generally done by anthropologists, the Eskimo with their pyramidal skulls, dull complexion, and flat noses are removed into a division by themselves Apart from these polar nomads, the American indigenes group roughly into a single race or division of mankind, of course with local variations If our attention is turned to the natives of Mexico especially, the unity of type will be found particularly close The native population of the plateau of Mexico, mainly Aztecs, may still be seen by thousands without any trace of mixture of European blood, and the following description may give a fair idea of their appearance[1] Their stature is somewhat low, estimated about 5 feet 3 inches, but they are of muscular and sturdy build Measurements of their skulls show them mesocephalic (index about 78), or intermediate between the dolichocephalic and brachycephalic (narrow and wide skulled) types of mankind The face is oval, with low forehead, high cheek bones, long eyes sloping outward towards the temples, fleshy lips, nose wide and in some cases flattish but in others aquiline, coarsely moulded features, with a somewhat stolid and gloomy expression Thickness of skin, masking the muscles, has been thought the cause of a peculiar heaviness in the outlines of body and face, the complexion varies from yellow-brown to chocolate (about 40 to 43 in the anthropological scale); eyes black, straight coarse glossy black hair, beard and moustache scanty Among variations from this type may be mentioned higher stature in some districts, and lighter complexion in Tehuantepec and elsewhere If now the native Americans be compared with the races of the regions across the oceans to their east and west, it will be seen that their unlikeness is extreme to the races eastward of them, whether white Europeans or black Africans On the other hand they are considerably like the Mongoloid peoples of North and East Asia (less so to the Polynesians), so that the tendency among anthropologists is now generally to admit a common origin, however remote, between the tribes of Tartary and of America This original connexion, if it may be accepted, would seem to belong to a long past period, to judge from the failure of all attempts to discover an affinity between the languages of America and Asia At whatever date the Americans began to people America, they must have had time to import or develop the numerous families of languages actually found there, in none of which has community of origin been satisfactorily proved with any other language group, at home or abroad In Mexico itself the languages of the Nahua nations, of which the Aztec is the best known dialect, show no connexion of origin with the language of the Otomi tribes, nor either of these with the languages of the regions of the ruined cities of Central America, the Quiché of Guatemala and the Maya of Yucatan Indeed, within the Mexican limits, there are various other languages which, so far as philological research can at present decide, are independent of one another The remarkable phenomenon of nations so similar in bodily make but so distinct in language can hardly be met except by supposing a long period to have elapsed since the country was first inhabited by the ancestors of peoples whose language has since passed into so different forms The original peopling of America may well date from the time when there was continuous land between it and Asia

---

[1] References may be found in Bancroft, *Native Races of the Pacific States*, vol. i. pp 24, 578, 618, 646

It would not follow, however, that between these remote ages and the time of the discovery of the New World by Columbus no fresh immigrants can have reached America We may put out of the question the Scandinavian sea rovers who sailed to Greenland about the 10th century, and appear afterwards to have coasted New England (see AMERICA, vol i p 706), but do not seem to have found their way far enough southward for their visit to have any effect on Mexico But at all times communication has been open from East Asia and even the South Sea islands to the west coast of America The importance of this is evident when we consider that Japanese junks now drift over by the ocean current to California at the rate of about one a year, often with some of the crew still alive (see C W Brooks in Bancroft, vol v p 51, *Overland Monthly*, San Francisco, 1872, p 353) Further north, the Aleutian islands offer a line of easy sea passage, while in north east Asia, near Behring s Strait, live Chukchi tribes who carry on intercourse with the American side the presence of Eskimo in this part of Asia (see Nordenskiold, *Voy of Vega*, vol ii pp 13, 81) is so plainly due to local migration that it is neglected in comparing the languages of the two continents Asiatics such as Japanese or Kurile Islanders, if they found their way in small numbers to America and merged into native tribes, might hardly leave descendants distinguishable from the rest of the population even in the first generation, nor introduce their own language Such assertions as that the Guatusos of Costa Rica are a tribe with fair skin and flaxen hair, and that Japanese words may be detected among the Indians of British Columbia, are examples of evidence which may be worth further sifting, but in an account like the present no proofs can be admitted unless far better authenticated than these What gives a more solid interest to the question of Asiatic influence in America, is that, though neither the evidence of features nor of language has substantiated it, there are details of Mexican civilization which are most easily accounted for on the supposition that they were borrowed from Asia They do not seem ancient enough to have to do with a remote Asiatic origin of the nations of America, but rather to be results of comparatively modern intercourse between Asia and America, probably since the Christian era Humboldt (*Vues des Cordilleres*, pl xxiii) compared the Mexican calendar with that in use in eastern Asia The Mongols, Tibetans, Chinese, and other neighbouring nations have a cycle or series of twelve animals, viz, rat, bull, tiger, hare, dragon, serpent, horse, goat, ape, cock, dog, pig, which may possibly be an imitation of the ordinary Babylonian Greek zodiac familiar to ourselves The Mongolian peoples not only count their lunar months by these signs, but they reckon the successive days by them, rat-day, bull day, tiger day, &c, and also, by combining the twelve signs in rotation with the elements, they obtain a means of marking each year in the sixty year cycle, as the wood rat year, the fire tiger year, &c. This method is highly artificial, consisting, not in mere numbering, but in combining series of different terms so that the same combination does not recur till the end of the period Thus the reappearance of its principle in the Mexican and Central American calendar (see p 212) is suggestive of importation from Asia Humboldt also discussed the Mexican doctrine, represented in the native pictures, of four ages of the world belonging to water, earth, air, and fire, and ending respectively by deluge, earthquake, tempest, and conflagration The resemblance of this to some versions of the Hindu doctrine of the four ages or yuga is of so remarkable a closeness as hardly to be accounted for except on the hypothesis that the Mexican theology contains ideas learnt from Asiatics Among Asiatic points of resemblance to which attention has since been called is the Mexican belief in the nine stages of heaven and hell, an idea which nothing in nature would suggest directly to a barbaric people, but which corresponds to the idea of successive heavens and hells among Brahmans and Buddhists, who apparently learnt it (in common with our own ancestors) from the Babylonian Greek astronomical theory of successive stages or concentric planetary spheres belonging to the planets, &c The Spanish chronicles also give accounts of a Mexican game called *patolli*, played at the time of the conquest with coloured stones moved on the squares of a cross shaped figure, according to the throws of beans marked on one side, the descriptions of this rather complicated game correspond closely with the Hindu backgammon called *pachisi* (see Tylor in *Jour Anthrop Inst*, vol viii p 116)[1]

The native history of Mexico and Central America is entitled to more respect than the mere recollections of savage tribes, inasmuch as here memory was aided by something like written record The Mexican pictures so far approached writing proper as to set down legibly the names of persons and places and the dates of events, while the rude drawings which accompanied these at least helped the professional historians to remember the traditions repeated orally from generation to generation Thus actual documents of native Aztec history, or copies of them, are still open to the study of scholars, while after the conquest interpretations of these were drawn up in writing by Spanish-educated Mexicans, and histories founded on them with the aid of traditional memory were written by Ixtlilxochitl and Tezozomoc, the most important of these picture writings, interpretations, and histories may be found in Kingsborough's *Antiquities of Mexico* In Central America the rows of complex hieroglyphs to be seen sculptured on the ruined temples probably served a similar purpose up to the time of the Spanish invasion The documents purporting to be histories, written down by natives in later times, thus more or less represent real records of the past, but the task of separating the preponderant mythical part from what is real history is of the utmost difficulty Among the most curious documents of early America is the *Popol Vuh* or national book of the Quiché kingdom of Guatemala, a compilation of traditions written down by native scribes, found and translated by Father Ximenez about 1700, and published by Scherzer (Vienna, 1857) and Brasseur de Bourbourg (Paris, 1861) This book, composed in a picturesque barbaric style, begins with the time when there was only the heaven with its boundaries towards the four winds, but as yet there was no body nothing that clung to anything else, nothing that balanced itself or rubbed together or made a sound, there was nought below but the calm sea alone in the silent darkness Alone were the Creator, the Former, the Ruler, the Feathered Serpent, they who give being and whose name is Gucumatz Then follows the creation, when the creators said "Earth," and the earth was formed like a cloud or a fog, and the mountains appeared like lobsters from the water, cypress and pine covered the hills and valleys, and their forests were peopled with beasts and birds, but these could not speak the name of their creators, but could only chatter and croak So man was made first of clay, but he was strengthless and senseless and melted in the water, then they made a race of wooden mannikins, but these were useless creatures without heart or mind, and they were destroyed by a great flood, and pitch poured down on them from heaven, those who were left of them being turned into the apes still to be seen in the woods After this comes the creation of the four men and their wives who are the ancestors of the Quichés, and the tradition records the migrations of the nation to Tulan, otherwise called the Seven Caves, and thence across the sea, whose waters were divided for their passage It is worth while to mention these few early incidents of the national legend of Guatemala, because their Biblical incidents show how native tradition incorporated matter learnt from the white men Moreover, this Central American document, mythical as it is, has an historical importance from its bringing in names belonging also to the traditions of Mexico proper Thus Gucumatz, "Feathered Serpent, corresponds in name to the Mexican deity Quetzalcoatl Tulan and the Seven Caves are familiar words in the Aztec migration traditions and there is even mention of a chief of Toltecat, a name plainly referring to the famed Toltecs, of whom further account will be given in their place in Mexican history Thus the legends of the *Popol Vuh* confirm what is learnt from comparing the culture of Central America and Mexico proper, that, though the nations of these districts were not connected by language, the intercourse and mixture between them had been sufficient to implant in them much common civilization, and to justify the anthropologist in including both districts in one region Historical value of the ordinary kind may be found in the latter part of the *Popol-Vuh*, which gives names of chiefs down to the time when they began to bear Spanish names, and the great city of Quiché became the deserted ruin of Santa Cruz The Maya district of Yucatan has also some vestiges of native traditions in the manuscript translated by D. Pio Perez (in Stephens, *Incidents of Travel in Yucatan*) and in the remarkable 16th century *Relacion de las Cosas de Yucatan* by Diego de Landa, published by Brasseur de Bourbourg (Paris, 1864) As in the Guatemala traditions, we hear of ancient migration from the Mexican legendary region of Tula, and here the leaders are four famous chiefs or ancestors who bear the Aztec name of the Tutul Xiu, which interpreted means "Bird Tree" Unfortunately for the historical standing of these four ancestors, there are in the Aztec picture writings representations of four trees each with a bird perched on it, and placed facing the four quarters, which make it probable that the four Tutul Xiu of tradition, in spite of the circumstantial detail of their wars and migrations, may be only mythic personifications of the four cardinal points (see Schultz Sellack in *Zeitsch f Ethn*, 1879, p 209) Nevertheless, part of the later Maya records may be genuine,—for instance, when they relate the war about three centuries before the Spanish conquest, when the king of Chichen Itza destroyed the great city of Mayapan Though the names and dates of Central American native kings have too little interest to general readers for traditions of them to be dwelt on here, they bring into view one important historical point, that the wondrous ruined cities of this region are not to be thought monuments of a perished race in a forgotten past, but that at least some of them belong to history, having been inhabited up to the conquest, apparently by the very nations who built them

---

[1] The appendix to Prescott s *Conquest of Mexico* contains an interesting summary of analogies between the civilization of Mexico and that of the Old World but some of the arguments are very inconclusive One which has been often cited turns on the likeness alleged by Naxera between the Chinese language and that of the Otomi nation of Mexico (whose name survives in that of their town Otompan, now Otumba) The examination of an Otomi grammar (such as *Elements de la Grammaire Othomi* Paris 1863) will however, convince the philological reader that the resemblance is hardly of an amount to found a theory of a Chinese connexion upon.

Turning now to the native chronicles of the Mexican nations, these are found to be substantial dated records going back to the 12th or 13th century, with some vague but not worthless recollections of national events from times some centuries earlier These last mentioned traditions, in some measure borne out by linguistic evidence of names of places, tribes, and persons, point to the immigration of detachments or branches of a widespread race speaking a common language, which is represented to us by the Aztec, still a spoken language in Mexico This language was called *nahuatl*, and one who spoke it as his native tongue was called *nahuatlacatl*, so that modern anthropologists are following native precedent when they use the term *Nahua* for the whole series of peoples now under consideration [1] Earliest of the Nahua nations, the Toltecs are traditionally related to have left their northern home of Huehuetlapallan in the 6th century, and, though this remote date cannot be treated as belonging to genuine history, there is other evidence of the real existence of the nation Their name *Toltecatl* signifies an inhabitant of *Tollan*, "land of reeds," a place which, as has been already pointed out, appears elsewhere in the national traditions of this region, and has a definite geographical site in the present Tulan or Tula, north of the valley of Anahuac, where a Toltec kingdom of some extent seems to have had its centre To this nation is ascribed not only the oldest but the highest culture of the Nahua nations, to them was due the introduction of maize and cotton into Mexico, the skilful workmanship in gold and silver, the art of building on a scale of vastness still witnessed to by the mound of Cholula, said to be Toltec work, the Mexican hieroglyphic writing and calendar are also declared to have been of Toltec origin With the Toltecs is associated the mysterious tradition of Quetzalcoatl, a name which presents itself in Mexican religion as that of a great deity, god of the air, and in legend as that of a saintly ruler and civilizer His brown and beardless worshippers describe him as of another race, a white man with noble features, long black hair and full beard, dressed in flowing robes He came from Tullan or from Yucatan (for the stories differ widely), and dwelt twenty years among them, teaching men to follow his austere and virtuous life, to hate all violence and war, to sacrifice no men or beasts on the altars, but to give mild offerings of bread and flowers and perfumes, and to do penance by the votaries drawing blood with thorns from their own bodies. Legend tells stories of his teaching men picture writing and the calendar, and also the artistic work of the silversmith, for which Cholula was long famed; but at last he departed, some say towards the unknown land of Tlapallan, but others to Coatzacualco on the Atlantic coast on the confines of Central America, where native tradition still keeps up the divine names of Gucumatz among the Quichés (see p. 208) and Cukulcan among the Mayas, these names having the same meaning as Quetzalcoatl in Aztec, viz., "Feathered Serpent." Native tradition held that when Quetzalcoatl reached the Atlantic he sent back his companions to tell the Cholulans that in a future age his brethren, white men and bearded like himself, should land there from the sea where the sun rises, and come to rule the country. That there is a basis of reality in the Toltec traditions is shown by the word *toltecatl* having become among the later Aztecs a substantive signifying an artist or skilled craftsman. It is further related by the Mexican historians that the Toltec nation all but perished in the 11th century by years of drought, famine, and pestilence, a few only of the survivors remaining in the land, while the rest migrated into Yucatan and Guatemala, where, as has been already pointed out, their name is commemorated in local records. After the Toltecs came the Chichimecs, whose name, derived from *chichi*, "dog," is applied to many rude tribes; the Chichimecs here in question are said to have come from Amaquemecan under a king named Xolotl, names which being Aztec imply that the nation was Nahua; at any rate they appear afterwards as fusing with more cultured Nahua nations in the neighbourhood of Tezcuco. Lastly is recorded the Mexican immigration of the seven nations, Xochimilca, Chalca, Tepaneca, Acolhua, Tlahuica, Tlascalteca, Azteca. This classification of the Nahuatlac tribes has a meaning and value. It is true that Aztlan, the land whence the Aztecs traced their name and source, cannot be identified by geographers, while the story of the separation of the seven nations at the place called Chicomoztoc or Seven Caves looks like national legend rather than real history. But the later stages of the long Aztec migration seem historical, and the map of Mexico still shows the names of several settlements recorded in the curious migration map published by Gemelli Careri (*Giro del Mondo*, Venice, 1728) and commented on by Humboldt; among these local names are Tzompanco, "place of skulls," now Zumpango in the north of the Mexican valley, and Chapultepec, "grasshopper hill," now a suburb of the city of Mexico itself, where the Aztecs are recorded to have celebrated in 1195 the festival of tying up the "bundle of years" and beginning a new cycle. The Aztecs moving from place to place in Anahuac found little welcome from the Nahua peoples already settled there, whose own history was indeed one of incessant jealousy and quarrel. One of the first clear events of the Aztec arrival is their being made tributary by the Tepanecs, in whose service or alliance they began to manifest their warlike prowess in the fight near Tepeyacac, where now stands the famous shrine of Our Lady of Guadalupe. Thus they overcame in arms the Acolhuas, their superiors in civilization, who had made Tezcuco a centre of prosperity and improvement. By the 13th century the Aztecs by their ferocity had banded their neighbours together against them; some were driven to take refuge on the reedy lake shore at Acoculco, while others were taken as captives into Culhuacan. The king of this district was Coxcoxtli, whose name has gained an undeserved reputation even in Europe as "Coxcox, the Mexican Noah," from a scene in the native picture writing where his name appears together with the figure of a man floating in a dug-out tree, which has been mistaken even by Humboldt for a representation of the Mexican deluge myth. Coxcoxtli used the help of the Aztecs against the Xochimilco people, but his own nation, horrified at their bloodthirsty sacrifice of prisoners, drove them out to live for years in want and misery on the islands and swamps of the great salt lagoon, where they are said to have taken to making their *chinampas* or floating gardens of mud heaped on rafts of reeds and brush, which in later times were so remarkable a feature of Mexico. As one of the Aztec chiefs at the time of the founding of their city was called Tenoch, *i.e.*, "Stone cactus," it is likely that from him was derived the name Tenochtitlan or "Stone-cactus place." Written as this name is in pictures or rebus, it probably suggested the invention of the well known legend of a prophecy that the war god's temple should be built where a prickly pear was found growing on a rock, and perched on it an eagle holding a serpent; this legend is still commemorated on the coins of Mexico. Mexico-Tenochtitlan, founded about 1325, for many years afterwards probably remained a cluster of huts, and the higher civilization of the country was still to be found among the other nations, especially among the Acolhuas in Tezcuco. The wars of this nation with the Tepanecs, which went on into the 15th century, were merely destructive, but larger effects arose from the expeditions under the Culhua king Acamapichtli, where the Aztec warriors were prominent, and which extended far outside the valley of Anahuac. Especially a foray southward to Quauhnahuac, now Cuernavaca, on the watershed between the Atlantic and Pacific, caused the bringing of goldsmiths and other craftsmen home to Tenochtitlan, which now began to rise in arts, the Aztecs laying aside their rude garments of aloe fibre for more costly clothing and going out as traders for foreign merchandise. In the 14th century the last great national struggle took place. The Acolhuas had at first the advantage, but Ixtlilxochitl did not follow up the beaten Aztecs but allowed them to make peace, whereupon, under professions of submission, they fell upon and sacked the city of Tezcuco. The next king of Tezcuco, Nezahualcoyotl, turned the course of war, when Azcapuzalco, the Tepanec stronghold, was taken and the inhabitants sold as slaves by the conquering Acolhuas and Aztecs; the place thus degraded became afterwards the great slave-market of Mexico. In this war we first meet with the Aztec name Moteuczoma, afterwards so famous in its Spanish form Montezuma. About 1430 took place the triple alliance of the Acolhua, Aztec, and Tepanec kings, whose capitals were Tezcuco, Mexico, and Tlacopan, the latter standing much below the other two. In fact the Aztecs now became so predominant that the rest of native history may be fairly called the Aztec period, notwithstanding the picturesque magnificence and intellectual culture which made Tezcuco celebrated under Nezahualcoyotl and his son Nezahualpilli. When the first Moteuczoma was crowned king of the Aztecs, the Mexican sway extended far beyond the valley plateau of its origin, and the gods of conquered nations around had their shrines set up in Tenochtitlan in manifest inferiority to the temple of Huitzilopochtli, the war god of the Aztec conquerors. The rich region of Quauhnahuac became tributary; the Miztec country was invaded southward to the Pacific, and the Xicalanca region to what is now Vera Cruz. It was not merely for conquest and tribute that the fierce Mexicans ravaged the neighbour lands, but they had a stronger motive than either in the desire to obtain multitudes of prisoners whose hearts were to be torn out by the sacrificing priests to propitiate a pantheon of gods who well personified their bloodthirsty worshippers. The desire for war captives as acceptable victims is related to have brought about an almost incredible agreement among nations of the Mexican alliance, that they should from time to time fight battles among themselves in order to provide prisoners for the altars. Thus there was something of the character of a religious war in the expedition made in 1469 under Axayacatl as far down the isthmus as Tehuantepec, whence the Mexican army came back with loads of rich plunder and thousands of captives, and the later ravaging of the Totonac region as far as the Atlantic, when the inhabitants were taken for sacrifice and their land recolonized by Aztecs. Ahuitzotl left the Aztec empire (as it is often somewhat ambitiously called) at the height of apparent power, but the cruel oppression of the subject regions had made their life almost unbearable, and the second Moteuczoma, coming to a rule already liable to break up from within, weakened it still more by upholding the class of chiefs or nobles against the common people who as warriors and traders had in great measure made the prosperity of the allied nations. The Mexicans had long tried to subjugate the stubborn little nation of Tlaxcallan (Tlascala), which had obstinately held out, though so hemmed in that for years the people lived without salt, this being no longer to be had from the sea coast. Moteuczoma made a last effort to crush them, but in vain, and when the Spaniards came they were there as ready made allies planted on the high road to Mexico. From the date when the festival of the new cycle was first celebrated in Chapultepec six 52 year periods had passed when in 1507 the new fire symbolizing the beginning of a new cycle was kindled for the last time on the breast of a human victim. Rumours of the coming of the Europeans may have before this date spread from Cuba, but in 1517 Cordova touched in Yucatan, and in 1518 Grijalva was on the east coast of Mexico, and the Aztecs first met the white men, in whom they saw, partly with hope and partly with fear, the fulfilment of the prophecy that Quetzalcoatl should one day return. With the Spanish conquest under Hernando Cortes (see CORTES) the native history of Mexico comes to an end.

---

[1] It should be noticed that this word is not etymologically connected with the somewhat similar word *Anahuac*, of which the meaning is given at page 206

CIVILIZATION

While the prairie tribes of America lived under the loose sway of chiefs and councils of old men, the settled nations of Mexico had attained to a somewhat highly organized government. This may be seen by the elaborate balance of power maintained in the federation of Mexico, Tezcuco and Tlacopan, where each king was absolute in his own country, but in war or other public interests they acted jointly with powers in something like the proportion in which they divided conquered lands and spoil, which was two fifths each to Mexico and Tezcuco and one fifth to Tlacopan. The successor of the Aztec king was customarily a chosen brother or nephew, the eldest having the first claim unless set aside as incompetent and having to be a tried warrior; this mode of succession, which has been looked on as an elaborate practical device for securing practical advantages, seems rather to have arisen out of the law of choice among the descendants of the female line, found in American tribes of much lower culture. Something like this appears in the succession of kings of Tezcuco and Tlacopan which went to sons by the principal wife, who was usually of the Aztec royal family. The Mexican chronicles, however show instances of the king's son succeeding, or of powerful chiefs being elected to the kingship. The term republic is sometimes used to describe the little state of Tlascala, but this was in fact a federation of four chiefs, with an assembly of nobles. In the Zapotec district the Wiyatao or high priest of Zopaa was a divine ruler before whom all prostrated themselves with faces to the ground; he was even too sacred to allow his foot to touch the earth, and was only seen carried in a litter.

The accounts given by the Spanish and native Mexican writers of the courts and palaces of the native kings must be taken with some reserve, from the tendency to use descriptive terms not actually untrue, but which convey erroneous ideas taken from European architecture; thus what are called columns of porphyry and jasper supporting marble balconies might perhaps be better described as piers carrying slabs, while the apartments and terraces must have been more remarkable for number and extent than architectural grandeur, being but low one-storied buildings. The principal palace of Mexico consisted of hundreds of rooms and halls ranged round three open squares, with women's apartments, granaries, storehouses, menageries, aviaries, of such extent that one of the companions of Cortes records having four times wandered about till he was tired, without seeing the whole. Not less remarkable was the palace of Tezcuco, surrounded with its groves and pleasure gardens; and, though now hardly anything remains of the buildings above ground, the neighbouring hill of Tezcotzinco still has its stone steps and terraces, and the immense embankment carrying the aqueduct channel of hewn stone which supplied water to basins cut in the solid rock still remains to prove that the chroniclers descriptions, if highly coloured, were at any rate genuine. Till the last century the gigantic figures of Axayacatl and his son Montezuma were to be seen carved in the porphyry hill of Chapultepec, but these as well as the hanging gardens have been destroyed, and only the groves of *ahuehuete* (cypress) remain of the ancient beauties of the place. That in the palace gardens flowers from the tierra caliente were transplanted, and water fowl bred near fresh and salt pools fit for each kind, that all kinds of birds and beasts were kept in well appointed zoological gardens where there were homes even for alligators and snakes,—all this testifies, not merely to barbaric ostentation, but to a cultivation of natural history which was really beyond the European level of the time. From the palaces and retinues of thousands of servants attached to the royal service may be inferred at once the despotic power of the Mexican rulers and the heavy taxation of the people; in fact some of the most remarkable of the picture writings are tribute rolls enumerating by hundreds and thousands the mantles, ocelot skins, bags of gold dust, bronze hatchets, loads of chocolate, &c., furnished periodically by the towns. Below the king was a numerous and powerful class of nobles, the highest of whom (*tlatoani*) were great vassals owing little more than homage and tribute to their feudal lord, while the natural result of the unruliness of the noble class was that the king to keep them in check increased their numbers, brought them to the capital as councillors, and balanced their influence by military and household officers, and by a rich and powerful merchant class. The nobles not only had privileges of rank and dignity, but substantial power over the plebeian or peasant class (*macehualli*), who submitted to much the same oppression and extortion at their hands as was customary in the Old World. The tenures of land in Mexico were those generally appearing in barbaric countries where invasion and military despotism have encroached on but not totally superseded the earlier tribal laws. The greatest estates belonged to the king, or had been granted to military chiefs whose sons succeeded them, or were the endowments of temples, but the *calpulli* or village community still survived, and each freeman of the tribe held and tilled his portion of the common lands. Below the freemen were the slaves, who were war captives, persons enslaved for punishment, or children sold by their parents. Prisoners of war were mostly doomed to sacrifice, but other classes of slaves were mildly treated, retaining civil rights, and their children were born free.

Justice. The superior courts of law formed part of the palace, and there were tribunals in the principal cities, over each of which presided a supreme judge or *cihuacoatl*, who was irremovable, and whose criminal decisions not even the king might reverse; he appointed the lower judges and heard appeals from them; it is doubtful whether he judged in civil cases, but both kinds of suits were heard in the court below, by the *tlacatecatl* and his two associates, below whom were the ward magistrates. Lands were set apart for the maintenance of the judges, and indeed nothing gives a higher idea of the elaborate civilization of Mexico than this judicial system, which culminated in a general court and council of state presided over by the king. The laws and records of suits were set down in picture writings, of which some are still to be seen; sentence of death was recorded by drawing a line with an arrow across the portrait of the condemned, and the chroniclers describe the barbaric solemnity with which the king passed sentence sitting on a golden and jewelled throne in the divine tribunal, with one hand on an ornamented skull and the golden arrow in the other. Among the resemblances to Old World law was the use of a judicial oath, the witness touching the ground with his finger and putting it to his lips, thus swearing by Mother Earth. The criminal laws were of extreme severity, even petty theft being punished by the thief being enslaved to the person he had robbed, while to steal a tobacco pouch or twenty ears of corn was death; he who pilfered in the market was then and there beaten to death, and he who insulted Xipe, the god of the gold and silver smiths, by stealing his precious metal, was skinned alive and sacrificed to the offended deity. Though aloe beer or "pulque" was allowed for feasts and to invalids in moderation, and old people over seventy seem to be represented in one of the picture writings as having liberty of drunkenness, young men found drunk were clubbed to death and young women stoned. Such a Draconian standard prevailing, it is hardly needful to enumerate the special penalties of such offences as witchcraft, fraud, removing landmarks, adultery, &c., which differed as to whether the criminal had his heart cut out on the altar, his head crushed between two stones, &c., while even lesser punishments were harsh, such as that of slanderers, whose hair was singed with a pine torch to the scalp.

Based on conquest as the Aztec kingdom was, and with the craving for warlike glory fostered by the most bloodthirsty religion the world ever saw, it follows that the nation was above all other pursuits organized as a fighting community. To be a tried soldier was the road to honour and office, and the king could not be enthroned till he had with his own hand taken captives to be butchered on the war god's altar at his coronation. The common soldiers were promoted for acts of daring, and the children of chiefs were regularly trained to war, and initiated by being sent into battle with veterans with whose aid the youth took his first prisoner, but his future rise depended on how many captives he took unaided in fight with warlike enemies; by such feats he gained the dignity of wearing coloured blankets, tassels, and lip jewels, and reached such military titles as that of "guiding eagle." The Mexican military costumes are to be seen in the picture writings, where the military orders of princes, eagles and tigers are known by their braided hair, eagles' beaks, and spotted armour. The common soldiers went into battle brilliant in savage war paint, but those of higher rank had helmets like birds and beasts of prey, armour of gold and silver, wooden greaves, and especially the *ichcapilli*, the quilted cotton tunic two fingers thick, so serviceable as a protection from arrows that the Spanish invaders were glad to adopt it. The archers shot well and with strong bows, though their arrows were generally tipped only with stone or bone; their shields or targets, mostly round, were of ordinary barbaric forms; the spears or javelins had heads of obsidian or bronze and were sometimes hurled with a spear thrower or *atlatl* of which pictures and specimens still exist, showing it to be similar in principle to those used by the Australians and Eskimo. The most characteristic weapon of the Mexicans was the *maquahuitl* or "hand wood," a club set with two rows of large sharp obsidian flakes, a well-directed blow with which would cut down man or horse. These two last mentioned weapons have the look of highly developed savage forms, while on the other hand the military organization was in some respects equal to that of an Asiatic nation, with its regular companies commanded each by its captain and provided with its standard. The armies were very large, an expedition often consisting of several divisions each numbering eight thousand men, but the tactics of the commanders were quite rudimentary, consisting merely of attack by arrows and javelins at a distance, gradually closing into a hand to hand fight with clubs and spears, with an occasional feigned retreat to draw the enemy into an ambuscade. Fortification was well understood, as may still be seen in the remains of walled and escarped strongholds on hills and in steep ravines, while lagoon cities like Mexico had the water approaches defended by fleets of boats, and the causeways protected by towers and ditches; even after the town was entered the pyramid temples with their surrounding walls were forts capable of stubborn resistance. It was held unrighteous to invade another nation without a solemn embassy to warn their chiefs of the miseries to which they exposed themselves by refusing the submission demanded, and this again was followed by a declaration of war, but in Mexico as in other more cultured countries this act of national morality degenerated into a ceremonial farce, where tribute was claimed from some neighbouring nation, or an Aztec god was offered to be worshipped in their temples in order to pick a quarrel as a pretext for an invasion already planned to satisfy the soldiers with lands and plunder, and to meet the priests' incessant demands for more human sacrifices.

Religion

Among the accounts of the Mexican religion are some passages referring to the belief in a supreme deity. The word *teotl*, god, has been thought in some cases to bear this signification, but its meaning is that of deity in general, and it is applied not only to the sun god but to very inferior gods. It is related that Nezahualcoyotl, the poet king of Tezcuco, built a nine storied temple with a starry roof above, in honour of the invisible deity called Tloquenahuaque "he who is all in himself," or Ipalnemoan, "he by whom we live," who had no image, and was propitiated, not by bloody sacrifices, but by incense and flowers. Those who adopt the opinion of Asiatic admixture in Mexican culture will use it to account for this remarkable religious phenomenon, less easily accounted for by native development, while also the appearance of a rival deity of evil, bearing the name of Tlacatecolotl, or "man owl," is mysterious. These divinities, however, seem to have had little or no place in the popular faith, which was occupied by polytheistic gods of more ordinary barbaric type. Tezcatlipoca was held to be the highest of these, and at the festival of all the gods his footsteps were expected to appear in the flour strewn to receive this sign of their coming. He was plainly an ancient deity of the race, for attributes of many kinds are crowded together in him, and he was prayed to in interminable formulas for help in war and for health and fortune, to deliver the nation from a wicked king, or to give pardon and strength to the penitent who had confessed his sins and been purified by washing. Between him and Quetzalcoatl, the ancient deity of Cholula, there had been old rivalry, as is related in legends of Quetzalcoatl coming into the land to teach men to till the soil, to work metals, and to rule a well ordered state; the two gods played their famous match at the ball game, and Tezcatlipoca, in the guise of a hoary headed sorcerer, persuaded the sick and weary Quetzalcoatl to drink the magic pulque that sent him roaming to the distant ocean, where he embarked in his boat and disappeared from among men. These deities are not easily analysed, but on the other hand Tonatiuh and Metztli, the sun and moon, stand out in the distinctest personality as nature gods, and the traveller still sees in the huge adobe pyramids of Teotihuacan, with their sides oriented to the four quarters, an evidence of the importance of their worship. The war god Huitzilopochtli, of whom one legend relates a supernatural conception in the ancient Tullan, while another story declares him to have been (like the Chinese war god) a deified warrior chief, was the real head of the Aztec pantheon; his idol remains in Mexico, a huge block of basalt on which is sculptured on the one side his hideous personage, adorned with the humming bird feathers on the left hand which signify his name, while the not less frightful war goddess Teoyaomiqui, or "divine war death," occupies the other side. Centeotl, the goddess of the all nourishing maize, was patroness of the earth and mother of the gods, while Mictlanteuctli, lord of dead land, ruled over the departed in the dim under world. Numbers of lesser deities presided over classes of society, events, and occupations of life, such as Tlazolteotl, goddess of pleasure, worshipped by courtesans, Tezcatzoncatl god of strong drink, whose garment in grim irony clothed the drunkard's corpse, and Xipe, patron of the goldsmiths. Below these were the usual crowd of nature spirits of hills and groves, whose shrines were built by the roadside to receive offerings from passers by. The temples were called *teocalli* or "god's house," and the teocallis of the greater deities rivalled in size as they resembled in form the temples of ancient Babylon. They were pyramids on a square or oblong base, rising in successive terraces to a small summit platform. The great teocalli of Huitzilopochtli in the city of Mexico stood in an immense square, whence radiated the four principal thoroughfares, its courtyard being enclosed by a square of which the stone wall, called the *coatepantli* or serpent wall from its sculptured serpents, measured nearly a quarter of a mile on each side. In the centre the oblong pyramid of rubble cased with hewn stone and cemented, 375 × 300 feet at the base, and rising steeply in five terraces to the height of 86 feet, showed conspicuously to the city the long processions of priests and victims winding along the terraces and up the corner flights of steps. On the paved platform were three story tower temples in whose ground floor stood the stone images and altars, and before that of the war god the green stone of sacrifice, humped so as to bend upward the body of the victim that the priest might more easily slash open the breast with his obsidian knife, tear out the heart and hold it up before the god, while the captor and his friends were waiting below for the carcase to be tumbled down the steps for them to carry home to be cooked for the feast of victory. Before the shrines reeking with the stench of slaughter, the eternal fires were kept burning, and on the platform stood the huge drum covered with snakes' skin, whose fearful sound was heard for miles. From the terrace could be seen seventy or more other temples within the enclosure, with their images and blazing fires, and the *tzompantli* or "skull-place," where the skulls of victims by tens of thousands were skewered on cross sticks or built into towers. There also might be seen the flat circular *temalacatl* or "spindle stone," where captives armed with wooden weapons were allowed the mockery of a gladiatorial fight against well armed champions. The great pyramid of Cholula with its hemispherical temple of Quetzalcoatl at the top, now an almost shapeless hill surmounted by a church, was about thrice as long and twice as high as the teocalli of Mexico. A large fraction of the Mexican population were set apart as priests or attendants to the services of the gods. The rites performed were such as are found elsewhere, prayer, sacrifice, processions, dances, chants, fasting and other austerities, but there are some peculiarities of detail. Prayers and other formulas have been copied down by Sahagun and other chroniclers, of endless prolixity, but not without occasional touches of pathos. The following are a few sentences from a prayer to Tezcatlipoca, interceding for the poor:—"O our lord, protector most strong and compassionate, invisible and impalpable, thou art the giver of life, lord of all, and lord of battles, I present myself here before thee to say some few words concerning the need of the poor people, the people of none estate or intelligence. . . . Know, O Lord, that thy subjects and servants suffer a sore poverty, that cannot be told of more than that it is a sore poverty and desolateness. The men have no garments nor the women to cover themselves with, but only rags rent in every part that let the wind and cold in. . . . If they be merchants, they now sell only cakes of salt and broken pepper; the people that have something despise their wares, so that they go out to sell from door to door and from house to house; and when they sell nothing they sit down sadly by some fence or wall, or in some corner, licking their lips and gnawing their nails for the hunger that is in them, they look on one side and the other at the mouths of those who pass by, hoping peradventure that one may speak some word to them. O compassionate God, the bed on which they lie is not a thing to rest upon, but to endure torment in, they draw a rag over them at night and so sleep. O our Lord, in whose power it is to give all content, consolation, sweetness, softness, prosperity, and riches, for thou alone art lord of all good, have mercy upon them, for they are thy servants. I supplicate thee that thou wilt lift up their heads with thy favour and aid, that thou wilt see good that they enjoy some days of prosperity and tranquillity so that they may sleep and know repose, having prosperous and peaceable days of life. Should this nation, for whom I pray and entreat thee to do them good, not understand what thou hast given, thou canst take away the good and pour out cursing so that all evil may come upon them, and they become poor, in need maimed, lame blind, and deaf, then indeed they shall waken and know the good that they had and have not, and they shall call upon thee and lean toward thee, but thou wilt not listen for in the day of abundance they would not understand thy goodness towards them. These prayers seem essentially genuine, indeed there was no European model from which they could have been imitated, but at the same time it must be remembered that they come down in Spanish writing, and not untouched by Spanish influence as in one passage where there is a mention of sheep an animal of course unknown to the native Mexicans. As to sacrifice, maize and other vegetables were offered, and occasionally rabbits quails &c, but, in the absence of cattle, human sacrifice was the chief rite, and cannibalism prevailed at the feasts. Incense was constantly used especially the *copalli* (copal) well known to us for varnish, little terra cotta censers are among the commonest of Mexican antiquities. Long and severe religious fasts were customary at special seasons, and drawing blood from the arms, legs and body by thrusting in aloe thorns and passing sharp sticks through the tongue, was an habitual act of devotion recalling the similar practices of devotees in India. The calendar of religious festivals for the whole course of the Mexican year has been preserved. Each 20 day period had one or more such celebrations. In the month of the "diminishing of waters the rain gods or Tlalocs were propitiated by a procession of priests with music of flutes and trumpets carrying on plumed litters infants with painted faces in gay clothing with coloured paper wings, to be sacrificed on the mountains or in a whirlpool in the lake. It is said that the people wept as they passed by, but if so this may have been a customary formality for the religion of these nations must have quenched all human sympathy. In the next month the god Xipe totec, already mentioned, had his festival called the "flaying of men" from the human victims being flayed after their hearts were torn out, for young men to dress in their skins and perform dances and sham fights. The succeeding festival of Camaxtli was marked by a severe fast of the priests, after which stone knives were prepared with which a hole was cut through the tongue of each, and numbers of sticks passed through. For the great festival of Tezcatlipoca the handsomest and noblest of the captives of the year had been chosen as the incarnate representative of the god and paraded the streets for public adoration dressed in an embroidered mantle with feathers and garlands on his head and a retinue like a king for the last month they married him to four girls representing four goddesses on the last day wives and pages escorted him to the little temple of Tlacochcalco where he mounted the stairs breaking an earthenware flute against each step this was a symbolic farewell to the joys of the world for as he reached the top he was seized by the priests his heart torn out and held up to the sun, his head spitted on the tzompantli and his body eaten as sacred food, the people drawing from his fate the moral lesson that riches and pleasure may turn into poverty and sorrow. The manner of the victim's death in these festivals afforded scope for variety, they dressed them and made them dance in character threw them into the fire for the fire god, or crushed them between two balanced stones at the harvest festival. The ordinary pleasures of festivals were mingled with all this, such as dances in beast masks, sham fights, and children's games but the type of a religious function was a sickening butchery followed by a cannibal feast.

writing

The Mexican priesthood, being the educated class were much concerned with the art of picture writing, which they had developed to a stage quite above the rude figures of the American hunting tribes and used systematically as a means of recording religious festivals and legends as well as keeping calendars of years and recording the historical events which occurred in them. Facsimiles of several of these interesting documents, with their translations may be seen in Kingsborough. On inspecting these it will be seen that their main principle is pictorial. Gods are represented with their appropriate attributes —the fire god h[illegible]rling his spear the moon goddess with a shell, &c the scenes of human life are pictures of warriors fighting with club and spear, men paddling in canoes women spinning and weaving, &c. An important step towards phonetic writing appears, however, in the picture names of places and persons. The simplest forms of these depict the objects signified by the name, as where *Chapultepec* or "grasshopper hill" is r[illegible] hopper on a hill, or a stone with a cactus on it stands for *Tenoch* or "stone cactus," the founder of *Tenochtitlan*. The system had, however, risen a stage beyond this when objects were drawn to represent not themselves, but the syllables forming their names, as where a trap, an eagle, a pricker, and a hand are put together not to represent these objects, but in order that the syllables of their names *mo quauh zo ma* should spell the word Moquauhzoma (see Aubin's introduction to Brasseur, *Hist du Mexique*, vol i p lxviii). The analogy of this to the manner in which the Egyptian hieroglyphs passed into phonetic signs is remarkable, and writing might have been invented anew in Mexico had it not been for the Spanish conquest. The Aztec numerals, which were vigesimal or reckoned by scores, were depicted by dots or circles up to 20, which was represented by a flag, 400 (a score of scores) by a feather and 8000 (a score of scores of scores) by a purse, but for convenience these symbols might be halved and quartered, so that 534 might be shown by one feather, one quarter of a feather, one flag, one half of a flag and four dots. The Mexican calendar depended on the combination of numbers with picture signs, of which the four principal were the rabbit, reed, flint, house—*tochtli acatl tecpatl, calli*. The cycle of 52 years was reckoned by combining these signs in rotation with numbers up to 13, thus —1 rabbit 2 reed 3 flint, 4 house 5 rabbit 6 reed &c. By accident this calendar may be exactly illustrated with a modern pack of cards laid out in rotation of the four suits as, ace of hearts, 2 of spades 3 of diamonds 4 of clubs, 5 of hearts, 6 of spades, &c. In the Mexican ritual calendar of the days of the year, the same method is carried further, the series of twenty day signs being combined in rotation with numbers up to 13, as this cycle of days only reaches 260 a series of nine other signs are affixed in addition, to make up the 365 day year. It is plain that this rotation of signs served no useful purpose whatever being less convenient than ordinary counting such as the Mexicans employed in their other calendar already mentioned, where the 20 day periods had each a name like our months, and their days had signs in regular order. Its historical interest depends on its resemblance to the calendar system of central and eastern Asia, where among Mongols Tibetans, Chinese, &c, series of signs are thus combined to reckon years, months and days for instance the Mongol cycle of 60 years is recorded by the zodiac or series of 12 signs—mouse bull tiger, &c, combined in rotation with the five male and female elements—fire, earth iron, water wood as "male fire bull year, &c. This comparison is worked out in Humboldt's *Vues des Cordilleres*, as evidence of Mexican civilization being borrowed from Asia. Naturally the Mexican calendar system lent itself to magic in the same way as the similar zodiac signs of the Old World, each person's fate being affected by the qualities of the signs he was born under, and the astrologer priests being called in to advise on every event of life. Of all Mexican festivals the most solemn was that of the *xiuhmolpilli*, or "year binding' when the 52 year cycle or bundle of years came to an end. It was believed that the destruction of the world, which after the Hindu manner the Mexicans held to have already taken place three or four times, would happen again at the end of a cycle. As the time drew near the anxious population cleansed their houses and put out all fire, and on the last day after sunset the priests dressed in the garb of gods set out in procession for the hill of Huixachtla there to watch for the approach of the Pleiades to the zenith, which gave the auspicious signal for the lighting of the new fire. The finest of the captives was thrown down and fire kindled on his breast by the wooden drill of the priest, then the victim's heart was torn out, and his body flung on the pile kindled with the new flame. The people watching from their flat housetops all the country round saw with joy the flame on the sacred hill and hailed it with a thank offering of drops of blood drawn from their ears with sharp stone flakes. Swift runners carried burning brands to rekindle the fires of the land, the sacred fire on the teocalli of the war god blazed up again, and the people began with feasting and rejoicing the new cycle.

Education.

Mexican education, at any rate that of the upper class, was a systematic discipline much under the control of religion, which here presents itself under a more favourable light. After the birth of a child, the *tonalpouhqui* or 'sun calculator' drew its horoscope from the signs it was born under, and fixed the time for its solemn lustration or baptism, performed by the nurse with appropriate prayers to the gods, when a toy shield and bow were provided if it was a boy, or a toy spindle and distaff if it was a girl, and the child received its name. An interesting picture writing, to be seen in Kingsborough, shows the details of the boy's and girl's education, from the early time when three small circles over the child show it to be three years old, and a drawing of half a tortilla or corn cake shows its allowance for each meal, as they grow older the lads are seen beginning to carry burdens, paddle the canoe, and fish, while the girls learn to spin and weave, grind maize, and cook,—good conduct being enforced by punishments of increasing severity, up to pricking their bodies with aloe thorns and holding their faces over burning chillis. The schools were extensive buildings attached to the temples, where from an early age boys and girls were taught by the priests to sweep the sanctuaries and keep up the sacred fires, to fast at proper seasons and draw blood for penance, and where they received moral teaching in long and verbose formulas Those fit for a soldier's life were trained to the use of weapons and sent early to learn the hardships of war, children of craftsmen were usually taught by their fathers to follow their trade, and for the children of nobles there was elaborate instruction in history, picture writing, astrology, religious doctrines, and laws

Marriages

Marriages depended much, as they do still in the East, on comparison of the horoscopes of the pair to ascertain if their birth signs were compatible Old women were employed as go betweens, and the marriage ceremony was conducted by a priest who after moral exhortations united the young couple by tying their garments together in a knot, after which they walked seven times round the fire, casting incense into it, after the performance of the marriage ceremony the pair entered together on a four days fast and penance before the marriage was completed

Funerals

The funeral rites of the Mexicans are best seen in the ceremonies at the death of a king The corpse laid out in state was provided by the priest with a jug of water for his journey, and with bunches of cut papers to pass him safely through each danger of the road—the place where the two mountains strike together the road guarded by the great snake and the great alligator, the eight deserts and the eight hills, they gave him garments to protect him from the cutting wind, and buried a little dog by his side to carry him across the nine waters Then the royal body was invested in the mantles of his patron gods, especially that of the war god, for Mexican kings were warriors on his face was placed a mask of turquoise mosaic, and a green chalchihuite stone as a heart between his lips In older times the dead king was buried on a throne with his property and dead attendants round him But after cremation came in a mourning procession of servants and chiefs carried the body to the funeral pyre to be burnt by the demon dressed priests after which the crowd of wives and slaves were exhorted to serve their lord faithfully in the next world were sacrificed and their bodies burnt Common people would not thus be provided with a ghostly retinue, but their simpler funeral ceremonies were as far as they went similar to those of their monarch

Agriculture and food.

The staple food of the Mexicans before the conquest has continued with comparatively little change among the native race, and has even been adopted by those of European blood Maize or Indian corn was cultivated on patches of ground where, as in the Hindu *jûm*, the trees and bushes were burnt and the seed planted in the soil manured by the ashes A sharp pointed planting stick a wooden shovel and a bronze bladed hoe called a *coatl* were the simple implements The Mexicans understood digging channels for irrigation, especially for the cultivation of the *cacahuatl*, from which they taught the Europeans to prepare the beverage *chocollatl*, these native names passed into English as the words cacao or cocoa, and chocolate Other vegetables adopted from Mexico are the tomata (*tomatl*) and the *chilli*, used as flavouring to native dishes The maize was ground with a stone roller on the grinding stone or *metlatl*, still known over Spanish America as the *metate* and the meal baked into thin oval cakes called by Aztecs *tlaxcalli* and by Spaniards *tortilla*, which resemble the *chapati* of India and the oat cake of Scotland The Mexicans were also skilful makers of earthen pots in which were cooked the native beans called by the Spanish *frijoles* and the various savoury stews still in vogue The juice extracted by tapping the great aloe before flowering was fermented into an intoxicating drink about the strength of beer, *octli*, by the Spaniards called *pulque*

Clothing and ornaments

Tobacco, smoked in leaves or cane pipes or taken as snuff, was in use especially at feasts It is related that in old times Mexican clothing was of skins or woven aloe and palm fibre, but at the time of the conquest cotton was largely cultivated in the hot lands, spun with a spindle, and woven in a rudimentary loom without a shuttle into the mantles and breech cloths of the men and the chemises and skirts of the women, garments often of fine texture and embroidered in colours Ornaments of gold and silver, and jewels of polished quartz and green chalchihuite were worn,—not only the ears and nose but the lips being pierced for ornaments

Metal-work

The artificers in gold and silver melted the metals by means of a reed blowpipe and cast them solid or hollow and were also skilled in hammered work and chasing, as some fine specimens remain to show, though the famous animals modelled with gold and silver fur, feathers, and scales have disappeared Iron was not known, but copper and tin ores were mined, and the metals combined into bronze of much the same alloy as in the Old World, of which hatchet blades and other instruments were made, though their use had not superseded that of obsidian and other sharp stone flakes for cutting, shaving, &c Metals had passed into a currency for trading purposes, especially quills of gold dust and T shaped pieces of copper, while cocoa beans furnished small change. The vast size of the market squares with their surrounding porticos, and the importance of the caravans of merchants who traded with other nations, show that mercantile had risen into some proportion to military interests

Art and pastime.

Nor was the wealth and luxury of Mexico and surrounding regions without a corresponding development of art The stone sculptures such as that remaining of Xochicalco, which is figured by Humboldt, as well as the ornamented woodwork feather mats, and vases, are not without artistic merit The often cited poems attributed to Nezahualcoyotl may not be quite genuine, but at any rate poetry had risen above the barbaric level, while the mention of ballads among the people, court odes, and the chants of temple choirs would indicate a vocal cultivation above that of the instrumental music of drums and horns, pipes and whistles, the latter often of pottery Solemn and gay dances were frequent, and a sport called the bird dance excited the admiration of foreigners for the skill and daring with which groups of performers dressed as birds let themselves down by ropes wound round the top of a high mast, so as to fly whirled in circles far above the ground The ball game of the Mexicans called *tlachtli*, was, like tennis, the pastime of princes and nobles, special courts were built for it, and the ball of india rubber (perhaps the first object in which Europeans became acquainted with this valuable material) might not be touched by the hands, but was driven against the walls by blows of the knee [illegible]

Central American culture.

in their state after the Spanish conquest are very scanty in comparison with the voluminous descriptions of Aztec life They bring out perfectly, however the fact of close connexion between the two civilizations Some Central American peoples were actually Mexican in their language and culture, especially the Pipils of Guatemala and a large part of the population of Nicaragua, but these were descendants of Aztecs or allied peoples who in the comparatively modern times of Aztec power invaded and colonized these distant countries (see Buschmann *Aztek Ortsnamen* viii, ix) With regard to the Central American nations proper, especially the Mayas of Yucatan and the Quiches of Guatemala, who dwelt in the cities and worshipped in the temples of Chichen Itza and Uxmal, Palenque and Copan the problem of Aztec connexion is deeper and obscurer How closely related these nations were in institutions to the Mexicans appears not only in their using the same peculiar weapons, such as the spear thrower and the toothed club or maquahuitl, but in the similarity of their religious rites such as drawing blood from their bodies as an act of penance and sacrificing human victims by cutting open the breast and tearing out the heart, the connexion is evident in such special points as the ceremony of marriage by tying together the garments of the couple or in holding an offender s face over burning chillis as a punishment the native legends of Central America make mention of the royal ball play which was the same as the Mexican game of tlachtli already mentioned At the same time many of the Central American customs differed from the Mexican thus in Yucatan we find the custom of the youths sleeping in a great bachelor s house an arrangement common in various parts of the world, but not in Mexico the same remark applies to the Maya exogamous law of a man not taking a wife of his own family name (see Diego de Landa *Relacion de Yucatan*, ed. Brasseur de Bourbourg, p 140) which does not correspond with Mexican custom We have the means of comparing the personal appearance of the Mexicans and Central Americans by their portraits on early sculptures vases, &c , and, though there does not appear any clear distinction of race type, the extraordinary back sloping foreheads of such figures as those of the bas reliefs of Palenque prove that the custom of flattening the skull in infancy prevailed in Central America to an extent quite beyond any such habit in Mexico It is from the ruined cities now buried in the Central American forests that we gain the best information as to the nations who built them The notion sometimes propounded that these famous cities were of great antiquity and the work of extinct nations has no solid evidence some of them may have been already abandoned before the conquest, but others were inhabited and by the ancestors of the Indians who now build their mean huts and till their patches of maize round the relics of the grander life of their ancestors In comparing these ruins through the districts of Yucatan Chiapas, Guatemala, and Honduras, it is evident that, though they are not the work of a single nation, but of two or more highly distinct in language, yet these nations had the great bond of a common system of pictorial or written characters One specimen of a Central American inscription may give a general idea of them all, whether it be from the sculptured façade of a temple sketched by Catherwood, or from the painted deerskin called the Dresden Codex (reproduced in Kingsborough) or from the chapter of Diego de Landa where he professes to explain and translate the characters themselves These consist of combinations of faces, circles, lines, &c , arranged in compartments in so complex a manner that [illegible]

in a complete way, Landa s description (p 320) gives a table of a number of their elements as phonetically representing letters or syllables but though there may be a partial truth in his rules, they are too insufficient or too erroneous to serve for any general decipherment Most of what has been written on this enticing subject is worthless, but a promising attempt has been made by E S Holden, who has analysed the combined figures into their elementary lines (*First Annual Report of Bureau of Ethnology* Smithsonian Institution, Washington 1881 see also Charencey *Melanges de Philologie et de Paleographie Americaines* Paris 1883) One point as to the Central American characters is clear that part of them are calendar signs recording dates From the accounts given by Landa and other writers it is plain that the Central American calendar reckoning the year in twenty eight periods of thirteen days, was the same in its principle of combining signs as that of Mexico here mentioned at page 212 The four leading Maya signs called *kan, mulu, ix cauac* corresponded in their position to the four Aztec signs rabbit reed, flint, house but the meanings of the Maya signs are unlike the Aztec very obscure A remarkable feature of the Central American ruins is the frequency of truncated pyramids built of hewn stone, with flights of steps up to the temple built on the platform at top The resemblance of these structures to the old descriptions and pictures of the Mexican teocallis is so striking that this name is habitually given to them The teocallis built by the Nahua or Mexican nations have been mostly destroyed but two remain at Huatusco and Tusapan (figured in Bancroft vol iv pp 443 456) which bear a strong resemblance to those of Palenque On the whole it is not too much to say that, in spite of differences in style the best means of judging what the temples and palaces of Mexico were like is to be gained from the actual ruins in Central America On the other hand, there are features in Central American architecture which scarcely appear in Mexican Thus at Uxmal there stands on a terraced mound the long narrow building known as the governor s house (Casa del Gobernador) 322 feet long 39 feet wide 26 feet high built of rubble stone and mortar faced with square blocks of stone the interior of the chambers rising into a sloping roof formed by courses of stonework gradually overlapping in a false arch ' The same construction is seen in the buildings forming the sides of a quadrangle and bearing the equally imaginary name of the nunnery (Casa de Monjas) the resemblance of the interior of one of its apartments to an Etruscan tomb has often been noticed (see Fergusson *History of Architecture* vol i Viollet le Duc in Charnay) Attempts to trace the architecture of Central America to direct derivation from Old World types have not been successful while on the other hand its decoration shows proof of original invention, especially in the imitations of woodwork which as the above mentioned architects have pointed out, passed into sculptured ornament when the material of construction became stone instead of wood Thus the architectural remains though they fail actually to solve the historical problem of the high culture of the nations round the Gulf of Mexico throw much light on it when their evidence is added to that of religion and customs Whether Mexican civilization was a barbaric copy of that which flourished in the now deserted Central American cities or whether the nations who built these cities themselves raised to a higher level a civilization derived from Mexico two things seem probable —first that the civilizations of Mexico and Central America were pervaded by a common influence in religion, art, and custom second, that this common element shows traces of the importation of Asiatic ideas into America

Among works of reference on the ancient history and civilization of Mexico and Central America may be mentioned H H Bancroft *The Native Races of the Pacific States of North America* London 1875 6 (contains the most complete summary with references to original authorities) Brasseur de Bourbourg *Histoire des Nations Civilisees du Mexique et de l Amerique Centrale* Paris 1857 59 (a valuable collection of materials but the author s own views are mostly fanciful) Prescott *History of the Conquest of Mexico* Clavigero *Storia Antica del Messico* Cesena 1780 (contains the substance of earlier writers such as Gomara Torquemada Acosta Boturini &c) For special topics —Lord Kingsborough *Antiquities of Mexico* London 1831 48 (contains facsimiles and interpretations of picture writings the native chronicles of Ixtlilxochitl and Tezozomoc a reprint of Sahagun &c) A von Humboldt *Vues des Cordilleres et Monumens des Peuples Indigenes de l'Amerique* Paris 1816 (Mexican civilization picture writing calendar &c) Travels and descriptions of antiquities &c —Dupaix (in Kingsborough) C Nebel *Viaje Pintoresco y Arqueologico sobre la Republica Mexicana* Paris 1839 F de Waldeck *Voyage Pittoresque et Archeologique dans la Province d Yucatan* Paris 1838 and *Palenque et Autres Ruines* Paris 1866 D Charnay *Cites et Ruines Americaines* avec texte par Viollet le Duc Paris 1863 J L Stephens *Incidents of Travel in Central America* &c New York 1841 *Incidents of Travel in Yucatan* New York 1858 Brantz Mayer *Mexico* New York 1854 Tylor *Anahuac, or Mexico and the Mexicans* London 1861, &c (L B T)

II THE REPUBLIC OF MEXICO

Mexico, Aztec *Mexitli* [1] (Estados Unidos de Mexico), is a federal republic in North America, bounded N by the United States (California, Arizona, and New Mexico), E by Texas and the Gulf of Mexico S by Guatemala and British Honduras, where the boundary lines are still partly undetermined, W by the Pacific Ocean Lying between 33° and 15° N lat and 87° and 117° W. long, Mexico stretches about 1950 miles north north west and south-south east, with a mean breadth of 400 miles, varying from about 1000 in 26° N to 130 at the narrowest part of the Tehuantepec isthmus It has a coast line of nearly 6000 miles,—about 4200 on the Pacific and 1600 on the Atlantic The seaboard is little varied either by deep inlets, bold headlands, broad estuaries, or large islands On the west side are the vast Gulf of California, in outline somewhat resembling the Red Sea, and so named by some of the early navigators, and the open Bay of Tehuantepec, besides the smaller inlets of Acapulco and San Blas, forming two of the finest harbours in the world, and almost the only safe ones in the republic On the east side the coast is mostly beset by lagoons and sandbanks, with no good havens, Campéche, Vera Cruz, Tampico, and Matamoras being all little better than open roadsteads exposed to the fierce "nortes,' or north easterly gales, that sweep the Gulf of Mexico for a great part of the year Of headlands the most prominent are Capes S Lucas and Palmas at the south extremity of Lower California, Corrientes south from San Blas, and Catoche in the north-east of Yucatan Besides this peninsula, which projects north north east, the only other is that of Lower California, which projects south south east parallel to the mainland The islands are few in number, and all of insignificant size, the most noteworthy being Tiburon and Angel de la Guarda in the Gulf of California, the uninhabited Revillagigedo group in the Pacific, and Cozumel off the Yucatan coast Mexico comprises altogether twenty seven confederate states, one territory, and the Federal District, with areas, populations, and chief towns as under [2]—

					Population (1877–80)
			139 140		9 700
		[illegible]	160 58	Chihuahua	12 116
		61 050	104 131	Saltillo	11 340
		14 363	194 861	Monterey	15 300
		[illegible]	144 747	Ciudad Victoria	7 800
		[illegible]	504 [illegible]	Jalapa	12 400
	Tabasco	12 16[illegible]	93 38	San Juan Bautista	6 800
	Campeche	26 083	86 299	Campeche	15 190
		[illegible]	285 384	Merida	32 000
		25 997	167 093	Culiacan	7 878
		48 367	994 900	Guadalajara	78 600
Pacific	Colima	2 393	65 827	Colima	23 572
	Michoacan	21,609	648 857	Morelia	20 400
	Guerrero	[illegible]	308 716	[illegible]	3 800
	Oajaca		718 194		26 228
		16 769	219 735	San Cristobal	8 000
		42 643	190 846	Durango	[illegible] 119
		26 585	413 603		32 000
		2 210	140 430		31 872
		[illegible]	506 799		34,300
			788 202		56 112
			179 915		27 560
			434 096		12,600
		9 598	636 038	Toluca	12 700
		1 898	154 946	Cuernavaca	16 320
		[illegible]	704 372	Puebla	64 588
	Tlaxcala	1,498	133 498	Tlaxcala	4,800
	Federal District	85	354 340	Mexico	241,110
	Lower California (Territory)	59 033	23 195	La Paz	2,396
		763 804	9 577 279		

Physical features. Plateaus and mountains.

Since the appearance of A von Humboldt's classic work on *New Spain*, as Mexico was called in the colonial times, this region has continued to be regarded as forming a main link in the vast chain supposed to stretch across the entire length of the American continent from Cape

---

[1] In this, as in all other Aztec names, the *x* (or *j*) represents the English sound *sh*, hence *Mexitli* and *Mexico* should be properly pronounced *Meshitli, Meshico* But they do not appear to have ever been so pronounced by the Spaniards, who naturally gave to the *x* its ordinary Spanish sound of the German *ch*

[2] These figures in the absence of scientific surveys and a trustworthy census are necessarily more or less approximate The areas are those of Ripley and Dana, based on A Garcia Cuba s *Carta geografica* (Mexico, 1874), the populations of the states and capitals are the estimates of Emiliano Busto in his *Estadistica de la Republica Mexicana* (Mexico, 1880) A writer in the *Times* of December 7, 1882, estimates the whole population at 12,000,000, much too high a figure

Horn to Behring's Strait But more recent research, and especially the surveys made by the French staff during the military operations between 1861–67,[1] have shown that this grand generalization must be abandoned In remote geological epochs a marine channel seems to have flowed between the northern and southern sections of the New World at the isthmus of Panama, while Mexico itself appears to be mainly a distinct geographical region of relatively recent upheaval Here there nowhere exists a continuous mountain range, to which might properly be applied the designation "Cordillera of the Andes," an expression which in any case is not current north of the isthmus of Tehuantepec Mexico forms, on the contrary, a vast table land, somewhat in the shape of a cornucopia, with its narrow end tapering to the south south east, its convex and concave sides facing the Pacific and Atlantic respectively, and with a general inclination northwards Most of the so called Cordilleras are merely the "cumbres" or escarpments of this plateau, which falls abruptly towards the Atlantic, and through a series of well marked terraces (formerly lacustrine basins) towards the Pacific Thus the carriage road from the capital runs in tolerably easy stages successively through the Tetla (8000 feet), Mescala (5500), Papagallo (1800), and Peregrino (1600) valleys down to Tepes within 40 miles of the seaport of San Blas But the southern central plateau of Anahuac maintains its mean elevation of 7000 to 8000 feet almost everywhere to within 35 or 40 miles of the Atlantic Hence the railway opened in 1873 between Vera Cruz and the capital has had to be carried by tremendously steep gradients to a height of nearly 8000 feet within a total distance of 263 miles[2] The general but gradual northerly tilt of the table land is shown by the altitudes of the capital, Durango, Chihuahua, and Paso del Norte on the United States frontier, which are respectively 7600, 6630, 4600, and 3800 feet

At the same time the scarps rise in many places considerably above the mean level of the plateau, which is itself intersected and broken into a number of secondary valleys by several short cross ridges, generally following the normal direction from north north west to south south east The most continuous range is the Sierra Madre of the Pacific, which may be traced at a mean elevation of over 10,000 feet from Oajaca to Arizona, and which from Guadalajara to the northern frontier is crossed by no carriage route Parallel to this is the Lower Californian range (Sierra de la Giganta, 3000 feet), which, however, falls abruptly eastwards, like the Atlantic escarpments The Californian peninsula seems to have been detached from the mainland when the general upheaval took place which produced the vast chasm now flooded by the Gulf of California Corresponding with the Sierra Madre of the Pacific on the west are the more interrupted eastern scarps of the central plateau, which sweep round the Gulf of Mexico as the Sierras Madres of Nuevo Leon and Tamaulipas at an elevation of about 6000 feet These are crossed by the carriage routes from Tula to Tampico (highest pass 4820 feet), from Saltillo to Monterey (3400), and at several other points

Of the central cross ridges the most important orographically and historically is the Cordillera de Anahuac,[3] which surrounds the Mexican (Tenochtitlan) and Puebla valleys, and which is supposed to culminate with Popocatepetl (17,853 feet) and Ixtaccihuatl (15,705)[4] But these giants belong to a different or rather a more recent system of igneous upheaval, running from sea to sea between 18° 59 and 19° 12 N in almost a straight line east and west, consequently nearly at right angles to the main axis of the central plateau The line is clearly marked by several extinct cones and by five active or quiescent volcanoes, of which the highest is Popocatepetl, lying south of the capital nearly midway between the Pacific and Atlantic East of this central point of the system are Citlaltepetl, better known as the Peak of Orizaba (17,176 feet), 70 miles inland, and San Martin or Tuxtla (9708 feet) on the coast south of Vera Cruz, to which correspond on the west the recently upheaved Jorullo (4000 feet) in Michoacan, Colima (12,800) near the coast in Jalisco, and the volcanic Revillagigedo group in the Pacific South of this line, and nearly parallel, are the Sierras of Guerrero, and south of the Tehuantepec isthmus those of Oajaca and Soconusco towards the Guatemala frontier In the same direction run the islands of Cuba and Hayti, which probably belong to the same Central-American system

Mexico is thus physically connected through its older plateau formations with the North American table lands, and through its more recent volcanic upheavals with the Central American igneous region But as it advances northwards this region loses in underground energy, hence, notwithstanding the remarkable upheaval of Jorullo in 1759, the Mexican cones show little signs of activity,[5] and the land is now scarcely ever wasted by violent earthquakes Such phenomena are most frequent in the Puebla valley, but, although often accompanied by the peculiar underground rumblings known as *bramidos*, they are seldom of a destructive character The natives speak of them rather as *temblores*, or "tremblings," than true *terremotos*[6]

Hydrography.

In a region where lofty ranges and plateau formations with steep escarpments approach almost everywhere to within a few miles of the coast, little space is left for the development of large river basins Most of the streams are little more than mountain torrents rushing impetuously from terrace to terrace seawards Many also flow through the profound rocky gorges or *barrancas*, as they are here called, which form a characteristic feature of the Mexican table lands[1] On the east side some of these barrancas, here running mostly west and east, attain depths of 800 to 1000 feet in the unfossiliferous limestones of that region, and even on the west coast the De Beltran cañon is flanked by sheer rocky walls over 500 feet high Hence the rivers are almost useless for irrigation purposes, and available as means of communication only for short distances in their lower reaches, where they flow through the narrow alluvial strips of level coast-lands to the sea Even the Rio Grande del Norte, which is by far the largest, and which forms the frontier line between Mexico and Texas, is navigable by large vessels only for a few miles above its port of Matamoras The Rio Grande de Santiago, the largest on the Pacific side, is almost every where obstructed by falls and rapids On this coast the next in importance is the Mercala, or Rio de las Balsas, which, like the Panuco, Alvaredo, Coatzacoalas, Grijalva, and Usumacinta flowing to the Gulf of Mexico, is subject to sudden freshets during the rains

---

[1] The results of these surveys are embodied in the *Carte du Mexique*, scale 1 3,000,000, published at Paris in 1873

[2] In the steepest parts the mean is 2 51 in 100, or 133⅓ feet to the mile The exact elevation of the capital above the sea at Vera Cruz appears to be 7550 feet, or 80 more than Humboldt's estimate

[3] The term *Anahuac*, meaning in Aztec "near the water, seems to have been originally restricted to the central lacustrine basin of Tenochtitlan But when the Aztecs reached both oceans they extended it to the Pacific coast between Tututepec and Guatemala (Anahuac Ayotlan), and to the Atlantic coast between the Alvarado and Tabasco rivers (Anahuac-Xicalanco) The original use of the word is still current amongst the natives as practically synonymous with Central Mexico As a strictly geographical expression it is vaguely and often incorrectly used by modern writers

[4] This elevation is based on the calculations of Humboldt, Glennie, and Gerolt but in 1857 Sonntag assigned an extreme height of over 17,000 feet to the highest peak of Ixtaccihuatl Popocatepetl is usually supposed to be the highest point of North America, but the recent United States surveys have transferred this honour to Mount Elias on the Alaska coast, which appears to be certainly over 19,000 feet high.

[5] Popocatepetl emits smoke, whence its name, meaning in Aztec "Smoking Mountain, from *popoca* ' to smoke, and *tepetl* " mountain Since the conquest three eruptions have been reported (1519, 1539, 1540), but the geological evidence seems to indicate that there has been no volcanic action for thousands of years Orizaba, whose native name means "Star Mountain, has been quiescent since 1566 Colima still frequently ejects ashes and smoke, but both Jorullo and Tuxtla are quiescent the last having been silent since the violent eruption of March 2 1793 Even the Mal pays, or hot district round Jorullo, has cooled down, and is now again clothed with vegetation

[6] It is noteworthy that the seismic waves flow normally along the indicated line from east to west, thereby confirming Humboldt's view that under about 19° N there is a deep rent in the earth's crust, through which at different periods the underground fires have broken at various points between the Gulf of Mexico and the Revillagigedo group "Only on the supposition that these volcanoes, which are on the surface connected by a skeleton of volcanic rocks, are also united under the surface by a chain of volcanic elements in continual activity, may we account for the earthquakes which in the direction mentioned cause the American continent, from the Gulf of Mexico to the Pacific Ocean, to oscillate at the same time' (Egloffstein, p 37).

At this season the waters which find no seaward outlet are collected in the depressions of the plateaus, where extensive tracts remain flooded for several months at a time But these lacustrine basins of the Anahuac and Chihuahua table lands, standing at elevations of from 4000 to 7000 feet, are, by evaporation under semi tropical suns, rapidly reduced to their normal level The diminished size of the Anahuac lakes shows that since the conquest a steady process of desiccation has been going on, due probably to the reckless destruction of the upland forests by the European settlers None of these lakes are of great size except Lake Chapala, which is traversed by the Rio Grande de Santiago, and has a reputed area of about 1300 square miles Amongst those of the plateau especially noteworthy for their magnificent scenery are Tezcuco and Chalco, in whose sparkling waters are reflected the surrounding volcanic peaks and extinct craters of the Anahuac table land, with a background formed by the Cordilleras, whose snowy summits rise here and there high above the dark pine forests of the lower slopes

Geology and minerals

In the higher ranges the prevailing formations are granites, which seem also to form the foundation of the plateaus, above which rise the traps, basalts, mineral bearing porphyries, and more recent lavas Hence Lyell's theory that Mexico consisted originally of granitic ranges with intervening valleys subsequently filled up to the level of the plateaus by subterranean eruptions Igneous rocks of every geologic epoch certainly to a large extent form the superstructure of the central plateau But the Mexican table land seems to consist mainly of metamorphic formations, which have been partly upheaved, partly interpenetrated and overlaid by igneous masses of all epochs, and which are chiefly represented by shales, greywacke, greenstones, silicious schists, and especially unfossiliferous limestone All these formations are alike remarkable for the abundance and variety of their metalliferous ores, such as silver, silver glance, copper, and gold Gneiss and micaceous schists prevail in Oajaca and on all the southern slopes facing both oceans But the highest ranges are formed mainly of plutonic and volcanic rocks such as granites, syenites, diorites, mineral bearing trachytes, basalts, porphyries, obsidian, pearlstone, sulphur pumice, lavas, tufa, and other recent volcanic discharges Obsidian (*itztli*) was the chief material formerly used by the natives in the manufacture of their cutting implements, as shown by the quarries of the Cerro de las Navajas ("Knife Cliff") near Zimapan Vast deposits of pumice and the purest sulphur are found at Huichapa and in many of the craters. But immeasurably the most valuable rocks are the argentiferous porphyries and schists of the central plateau and in Sinaloa, unless they are destined to be rivalled by the auriferous deposits of Sonora[2] Horizontal and stratified rocks, of extremely limited extent in the south, are largely developed in the northern states, and chalk becomes very prevalent towards the Rio Grande and Rio Gila valleys. To this chalk and to the sandstones are probably to be referred the sandy plains which cover vast tracts in North Mexico, stretching thence far into New Mexico and Texas. Here the Bolson de Mapimi, a vast rocky wilderness inhabited only by wild tribes, occupies a space of perhaps 50,000 square miles in Coahuila and parts of the surrounding states

None of the horizontal layers seem to be very rich in ores, which are found mainly in the metamorphic, palæozoic, and hypogene rocks of Durango, Chihuahua, and the south. Apart from Sinaloa and Sonora, which are now known to contain vast stores of the precious metals, nearly all the historical mines lie on the south central plateau at elevations of from 5500 to 9500 feet A line drawn from the capital to Guanajuato, and thence northwards to the mining town of Guadalupe y Calvo in Chihuahua, and southwards to Oajaca, thus cutting the main axis of upheaval at an angle of 45°, will intersect probably the richest known argentiferous region in the whole world The central group of mines in the three mineral districts of Guanajuato, Zacatecas, and Catorze (San Luis Potosi), which have yielded more than half of all the silver hitherto found in Mexico, lie between 21° and 24° 30′ N, within an area of about 13,000 square miles Here the Veta Madre lode of Guanajuato alone produced £504,000 between 1556 and 1803, besides £10,000 of gold This metal, however, occurs chiefly, not on the plateau in association with silver, but on the slopes facing the Pacific, and apparently in greatest abundance in Sonora, near the auriferous region of New California In recent times over half of the silver produced in the whole world has been supplied by Mexico, and the total yield of the precious metals between 1537 and 1880 was as under [3]—

	Gold	Silver	Total
1537 to 1821	£14,000 000	£418 000,000	£432,000,000
1821 to 1880	10,000 000	180,000,000	190,000,000
Total	£24,000,000	£598,000,000	£622,000,000

Of other minerals the most important are copper, found in a pure state near the city of Guanajuato, and associated with gold in Chihuahua, Sonora, Guerrero, Jalisco,

---

[1] "Near the mountain ranges, from which the water after heavy rains rushes down in innumerable forest streams these ravines are filled with incredible rapidity as high as 30 feet —the torrent importing (*sic*) trees and bearing away rocks with a thundering noise and irresistible power" (Egloffstein p 22)

[2] On the general character and distribution of the igneous formations Von Egloffstein remarks "Intimate relations exist between the metalliferous and non metalliferous porphyries The metalliferous porphyry is less frequent but constitutes the most important formation, bearing the precious metals, embracing the rich lodes of Real del-Monte, Pachuca, Chico Capula, and Santa Rosa, all of great richness and magnitude They further form the mineral districts of Augangueo, Oro, Huautla &c and part of the mountains of Zimapan and Istapa del Oro The lodes found in this porphyry are characterized by their magnitude and the consistency of the ores they contain . The richest ores of native silver and sulphuret chloride, and oxide of silver are found in the lodes of Real del Monte Pachuca, and Santa Rosa The gold seems to exist in small particles in the meta morphic porphyry mountains, whence it is carried by the rains to the valleys as the rocks become disintegrated' (pp 6–8)

[3] *Times* correspondent, December 7 1882 Guanajuato seems to be still the greatest producer, yielding from £1,500,000 to £1,750,000 yearly, although the great Valenciana mine is flooded, and of the hundred opened only fifty-two are now worked (Geiger).

Michoacan, and elsewhere, iron in immense masses in Michoacan and Jalisco, and in Durango, where the Cerro del Mercado is a solid mountain of magnetic iron ore, lead associated with silver, especially in Oajaca, tin in Michoacan and Jalisco, sulphur in many craters, platinum recently found in Tlaxcala and Hidalgo, cinnabar also recently in Morelos and Guerrero, "steppe salt" in the sandy districts of the north, "bitter salt" at Tepeyac, coal in limited quantities at various points, bismuth in many parts, marble, alabaster, gypsum, and rock salt in great abundance throughout the plateau and the sierras In 1882 there were open altogether 569 mines —541 silver, 14 gold, 4 copper, 4 lead, 3 salt, 2 coal, and 1 mercury [1]

Intersected about midway by the Tropic of Cancer, and stretching across seventeen parallels of latitude, Mexico, from its position alone, necessarily enjoys a great diversity of climate But from its peculiar configuration this feature is affected far more by the relief of the land than by its distance from pole or equator This is especially true of the more fertile and populous section lying within the torrid zone, where three distinct climatic regions are distinguished, not according to their horizontal, but according to their vertical position The temperature falling steadily with the elevation of the land, which here rises rapidly from sea level to nearly 18,000 feet above the surrounding waters, the low lying coast lands, up to about 3000 feet on the scarps and terraces of the central plateau, are comprised within the first zone of *tierras calientes*, or "hot lands" Within this zone are included all the sandy and marshy tracts fringing the Gulf of Mexico, the lower slopes facing eastwards and exposed to the hot and moist winds from the Caribbean Sea, and most of Yucatan and the Tehuantepec isthmus, besides the narrow strip between the uplands and the Pacific which broadens northwards along the east side of the Gulf of California Here the mean temperature varies from 77° to 82° Fahr, seldom falling below 60°, but often rising to 105°, and in the sultry districts of Vera Cruz and Acapulco to 110° The extreme north western parts of this region come almost within the rainless zone, and the Californian peninsula itself is subject to excessive droughts, rendering it almost uninhabitable But farther south the climate on both seaboards may be described as humid, hot, and extremely unhealthy, especially for Europeans Yellow fever and black vomit are here endemic But these scourges are at least compensated by a magnificent tropical vegetation and extensive virgin forests abounding in valuable timbers, dyewoods, and medicinal and other useful plants Of the 114 species of trees and cabinet woods, 17 of oil bearing plants, and over 60 of medicinal plants and dyewoods indigenous to Mexico, and often differing specifically from kindred varieties in Central and South America, by far the larger part are represented in the tierras calientes Amongst the most important of these forest plants are mahogany, rosewood, copal, caucho (india rubber), jalap, sarsaparilla, and vanilla. Here also maize, supplying the staple food of the people, yields prodigious returns, multiplying from two hundred to four hundred fold, and affording two, three, and even four successive crops within the year Rice, indigo, cotton, tobacco, and coffee all thrive well, while sugar, cocoa, the banana, and several varieties of beans are largely cultivated The tobacco of Vera Cruz and Tabasco, the coffee of Colima, and the cocoa of Oajaca and Chiapas are of unrivalled excellence

To the "hot lands" succeed in vertical position the *tierras templadas*, or "temperate lands, which comprise all the higher terraces and the central plateaus themselves between about 3000 and 8000 feet With a mean temperature of from 62° to 70° Fahr, and oscillating between such moderate extremes as 50° and 86°, this region enjoys one of the very finest climates on the globe The Puebla and Anahuac table lands are described by enthusiastic travellers as "terrestrial Edens," with a perennial spring symbolized by the evergreen oak, cedars, and many analogous plants, which here attain their greatest perfection The transition from the lower zone is often very gradual, and, while endemic fevers cease altogether at altitudes of 2700 and 2800 feet, the tropical flora invades many parts of the terrace lands, and even of the plateaus to heights of 4000 and 5000 feet [2] A certain uniformity is thus imparted to the Mexican landscape by the wide range of the maize, wheat, tobacco, vine, coffee, and other plantations, as well as by the palms, evergreens, mango, olive, orange, lemon, yucca, and an endless variety of the cactus family, one species of which forms hedges 20 feet high on the Anahuac uplands The central zone is on the whole drier than the southern lowlands, although the scarps facing seawards are often wrapped in the fogs and mists of the intercepted moisture charged atmospheric currents The heaviest recorded rainfall (90 to 100 inches) occurs in the healthy Huatusco district of Vera Cruz, at an altitude of 4380 feet

In the highest zone of *tierras frias* or "cold lands," embracing all the highlands from about 8000 feet upwards, the rainfall is five times less than on the tierras templadas Hence snow rests throughout the year only on the four most elevated peaks of Popocatepetl, Orizaba, Nevada de Toluca (15,000 feet), and Ixtaccihuatl Characteristic both of the tierras frias and templadas is the maguey (*Agave mexicana*), whose fruit is edible, and whose fermented juice has from time immemorial supplied the famous *pulque*, or national beverage of the Mexicans. From the fibre of the heniquen, an allied species, is produced the "Sisal hemp of commerce, which has in recent years become the staple export of Yucatan

Speaking generally, the four seasons are clearly marked north of 28° N lat only South of that parallel they merge in the *estacion de las aguas*, or rainy season, from May to October, and the *estacion seca*, or dry season, which prevails for the rest of the year The rains generally begin on the east coast, gradually moving westwards In the Pacific the moist atmospheric currents are deflected northwards, whence the striking contrast between the wooded slopes of British Columbia and the treeless crests of the arid Lower Californian peninsula

---

[1] Lorenzo Castro *Mexico in* 1882 According to this authority the total yield of the Mexican mines between 1537 and 1880 was £776,276 000, while another estimate based on a report of the Mexican mint gives it at £930 786,000 Of this a large amount has been coined in Mexico, where there were eleven mints at work in 1876 with a total annual yield of about £5,000 000 The total coinage since the conquest has been estimated as high as £600 000 000 not more than 5 per cent of this being gold With regard to coal, the existence of which in Mexico has been recently denied by Mr Bigelow in *Harper's Magazine*, official returns for 1882 give a list of over twenty places where it has been found, though nowhere as yet in large quantities Petroleum also appears to be very abundant in several localities Amongst other natural products mention should be made of amber, found on the Yucatan coast Mineral springs are very numerous everywhere on the plateaus and terrace lands The most famous are El Peñon and N Señora de Guadelupe near the capital, and Aguas Calientes farther north

[2] On the Amilpas plateau which stretches south of Popocatepetl at a mean height of 5000 to 5400 feet ' coffee sugar, and indigo are cultivated, and most of the tropical fruits grow luxuriantly (Egloffstein, p 17) The same authority gives the limits of vegetation in this region at 12,614 feet, and the snow line at 14 960 feet He observes that "nothing is more surprising to the traveller than the varieties of climate under this zone, which vary according to the different elevations above the sea In a few hours we descended from the cold regions of the fir and the oak, on the heights of Ozumba, to a hot climate, *tierra caliente*, where we found the most luxuriant vegetation, passing in that short time through successive changes of the most diversified species of trees, plants, birds, insects (p 22)

In its fauna no less than in its flora Mexico forms a land of transition between North and Central America In common with the north it has several varieties of the bear, the wolf, coyote, skunk, bison, squirrel, beaver, marten, otter rattlesnake, heloderm,[1] mocking bird, and many wild fowl while its monkeys (five species), puma, *jaguar, ocelot*, sloth, *tapir, alligators* (*two* species), iguana, boa, scorpions, tarantulas, and numerous brilliantly coloured parrots, trogons, and humming birds connect it with the southern regions Peculiar to Mexico, and distinguishing it from most tropical and subtropical lands, are its songsters, of which, besides the mocking bird (*zenzontl*), as many as twenty species have been enumerated The coasts are well supplied with fish and turtles, while the pearl fisheries of the Gulf of California continue to be a source of wealth to that otherwise unproductive territory, yielding in 1875 pearls to the value of £16,000, and £28,000 worth of shells All the European domestic animals thrive well, and vast herds of cattle, horses, and sheep are found on the well stocked ranchos of the northern states Here some of the more prosperous breeders own from twenty to thirty thousand head of oxen, and next to the precious metals hides and cattle are among the chief articles of export

Agriculture. But in the south stock breeding yields everywhere to agriculture as the chief occupation of the people Being largely volcanic, the soil is here extremely fertile wherever water can be had in sufficient quantities for irrigation purposes Next to maize, which with beans and chilli forms the almost exclusive food of the Indians, the most important crop is probably sugar, of which over 60 million pounds are annually produced in the state of Morelos alone Coffee is extensively cultivated on the lower slopes, and now exported in considerable quantities, especially to the United States The tobacco and cotton crops are yearly increasing in importance, while from the maguey is extracted, besides pulque, a spirit called mezcal to the annual value of about £750,000 The aborigines are partly employed as free labourers on the plantations, and partly hold small plots liable to a light Government tax The food crops thus raised were valued in 1873 at £14,500,000, the agricultural produce at £30,000,000, and the landed property at £85,000,000, but the last item was estimated by the minister of finance at fully three times that sum The value of arable freehold land was stated in 1882 to be from £1 to £3 per acre, according to its proximity to or remoteness from rivers

Industries Of the industries strictly so called those directly connected with agricultural interests have alone acquired any considerable development Such are sugar refining carried on on a vast scale especially in Morelos brewing and distilling chiefly from maguey paper making from various pulps and fibres grist mills and saw mills especially in Puebla Queretaro Guadalajara and Saltillo A few iron foundries have been at work for some years and stout hand woven cotton and woollen fabrics are produced in many of the large towns The rebozos (shawls) of Leon and Salvatierra have a wide repute while Texcoco and Puebla are noted for their porcelain and glass ware Among the petty industries are clay and rag figures artificial flowers wooden toys, and gold filigree work in the production of which the natives often display remarkable taste and skill

But all these manufactured wares are solely intended to supply the local wants so that the exports have hitherto been restricted almost exclusively to the produce of the land and of the mines Of the former the chief items are coffee Sisal hemp tobacco hides, lumber, cochineal indigo and other dyes sarsaparilla, vanilla, orchil india rubber But the precious metals still continue to constitute fully two thirds of all the exports which in 1882 had a total estimated value of about £6,000,000 In the same year an equal sum represented the imports, the leading items of which were cotton, linen, silk, and woollen goods, metals, hardware, machinery, and provisions Although diplomatic and consular relations with Great Britain have been suspended since 1867, that country still

about

in descending order, is the trade with the United States, France, Germany, Spain, and Columbia

Probably four fifths of the exchanges now pass through Vera Cruz, which, since the opening of the railway to the Anahuac plateau, has become the natural out port of the capital and all the central states It is connected by several lines of ocean steamers with Liverpool, Southampton, St Nazaire, and the Atlantic States of North America On the Pacific seaboard, where the trade is largely in German hands, Acapulco and the other ports also enjoy regular steam communication with San Francisco and Panama No accurate returns are available of the shipping, but the yearly arrivals in all the Mexican ports are stated to average about five thousand,—not more than one fifth under the national flag

Communication Till recently the means of internal locomotion were mainly limited to the wretched bridle paths from the central plateau over the sierras and terrace lands down to a few points on both coasts, and to twenty four regular lines of diligences under one management But since the completion of the line from Vera Cruz to the capital, with a branch to Puebla, the Mexican railway system has acquired a considerable development The Inter Oceanic line across the Tehuantepec isthmus is in progress, the Great Central Trunk line running northwards through Chihuahua will ere long effect a junction with the North American net work, and at the end of 1882 there had been opened to traffic altogether 2219 miles For that year the number of passengers carried was 8,250,000, and of merchandise 273 million tons, with net earnings £940,000, or £800 per mile Still more developed is the telegraph system, which is now extended to all the state capitals, and through the Mexico Matamoras line to the United States and the rest of the world The 8150 miles open in 1882 forwarded 750,000 messages, or in the proportion of 8 per 100 inhabitants

Finance. For the same year the estimated revenue was £6,140,000, and expenditure £6 300 000 The foreign debt is stated to be £19,600,000, and the internal about £10,000,000, or altogether at the rate of £3 per head of the population Most of the foreign debt is owned in England, but the British claims had long been practically repudiated by the Mexican Government At the end of 1882, however, a semi official suggestion was made that a settlement might be effected by Mexico paying 1 per cent on the capital for the first ten years, 2 for the second, and 3 thereafter the whole sum, amounting to £16,000,000, to be liquidated in fifty years[2] The revenue is chiefly derived from the customs, and about £1 750 000 of the expenditure is absorbed by the army, the peace footing of which is 22 500 men of all arms Beyond a few coastguard steamers maintained mainly for revenue purposes, there is no navy An indication of financial improvement is afforded by the establishment in 1882 of the Mexican National Bank by a French company with a capital of £4,000 000 This bank is privileged to issue paper money up to £12,000 000, in return allowing the supreme executive to overdraw their account up to £2 000,000 A further symptom of revival is presented by the increasing business of the general post office, which in 1880 forwarded 4 406 000 letters and packages through 873 offices

Education. Education also has made marked progress since the final separation of church and state in 1857 In that year the old university of Mexico a purely ecclesiastical institution after the model of Salamanca and the Sorbonne, was abolished, or rather was replaced by special schools of law, medicine, letters, agriculture, mines, sciences, fine arts, and commerce, and a military college These, as well as numerous lower schools, including two hundred in the capital alone are all maintained by the state, while national schools are supported by public grants in all the large towns, and higher institutions in the capitals of the several states There are in all nearly five thousand public schools besides establishments for the deaf and dumb the blind and juvenile delinquents, and numerous charitable foundations maintained by voluntary contributions.

Religion. Roman Catholicism, which under the Spanish rule was alone tolerated, continued after the separation to be the state religion till 1857 Since then, while all churches enjoy equal protection, none are officially recognized The great majority of the *Indios fideles*, mestizoes, and creoles still adhere at least outwardly to the Roman Church, which is administered by a hierarchy of three archbishops (Mexico, Morelia and Guadalajara) and twelve bishops. But by the organic laws of 1856 and 1859 all ecclesiastical estates, at one time comprising over one third of the soil, were nationalized, the regular clergy suppressed, and their monasteries, together with all other superfluous ecclesiastical structures, appropriated by the state During the last few years American Protestant missions have claimed some partial success and the so called Church of Jesus, an undenominational body of a somewhat original type, has found a number of adherents especially on the Anahuac table land But the *Indios bravos*, or uncivilized aborigines, everywhere follow the old spirit worship while the Christianity of the Fideles is little more than a cloak for the continuous practice of the former Aztec heathenism The pomp of the Roman ritual is supplemented by the feasts of the national worship and the Pagan deities of the old cult are still represented by the saints of the Roman calendar [1]

---

[1] A specimen of this curious creature, the only known venomous lizard (*Heloderma suspectum*), reached the London Zoological Gardens in 1882, its habitat is the north of Mexico, and New Mexico, Arizona, and Texas

[2] This advance towards a settlement was put forward in the *Two Republics* of December 5, 1882, a Mexican journal which reflects the views of the Government on all matters of foreign policy.

Administration

Mexico constitutes at present a confederation of states modelled on that of the North American Union, and administered according to the constitution of 1857 as amended in 1873–74 By popular suffrage are chosen the president, the upper house (fifty two members) and the supreme judiciary for four years and the lower house (two hundred and twenty seven members) for two years The senate, abolished in 1853, was restored in 1874, and the chief justice is *ex officio* vice president The federal states, which are divided into a number of administrative districts, enjoy full autonomy in all local matters The several constitutions are modelled on that of the central government, and like it comprise three departments—legislative, executive, and judicial Each state is represented in the federal congress in the proportion of one member for every 80,000 inhabitants and in the federal senate by two members elected by suffrage in the local congress All external affairs and questions of general interest are reserved for the central government The constitution as now established thus represents in theory the complete overthrow of mediævalism, and the absolute triumph of the new ideas which in the Old World are still in so many places struggling for the ascendency

History Colonial period

It is this struggle between privilege and popular rights that lends its human interest to the otherwise monotonous record of unresisted oppression and apparently aimless revolutions which characterize the early and the later periods of Mexican history from the overthrow of the native rule down to the present day The early or colonial period covers exactly three hundred years—from the death in 1521 of Guatemozin last of the Aztec emperors, to the withdrawal of the last Spanish viceroy Don Juan O Donoju, in 1821 During these three centuries the attitude of the masses was one rather of sullen submission than of active resistance to grinding oppression By the Spanish Government Mexico was looked on merely as a vast metalliferous region, to be jealously guarded against foreign intrusion and worked exclusively for the benefit of the crown The natives were evangelized chiefly for the purpose of being employed as slaves above and below ground and thus was introduced from the West Indies the system of *repartimientos*, or distribution of the aborigines on the plantations and in the mines But while this system proved fatal to the natives of Cuba and Hayti, where it had to be replaced by negro labour the hardier populations of the Anahuac plateau successfully resisted its blighting influences It proved in fact more disastrous to the oppressor than to the oppressed In those days Spain was commonly compared to a sieve, never the richer for all the boundless wealth drawn from the New World But the aborigines derived at least some advantage from contact and partial fusion with a people of superior culture This fusion, which may be regarded as the chief outcome of the colonial administration, has contributed to the formation of the present exceedingly complex Mexican nationality, in which the Indian continues to be the predominating element Taking the whole population at less than ten millions, its ethnical distribution appears to be at present as under —

1	Full blood Indians	5 000,000
2	Mestizoes (half caste Indians and whites)	3 000 000
3	Creoles (whites of Spanish descent)	1 500 000
4	Gachupines [2] (Spaniards by birth)	50 000
5	Other Europeans and Americans	100 000
6	Full blood negroes	10 000
7	Zambos or 'Chinos (Indo Africans)	45 000
8	Mulattoes (Eurafricans)	5 000

Under the Spanish administration, which was marked on the surface by few stirring events such as warlike expeditions, civil strife, or serious internal troubles, Mexico, or New Spain, formed a viceroyalty at one time stretching from the isthmus of Panama to Vancouver s Island Antonio de Mendoza, appointed in 1535 after government by *audiencias* had proved a signal failure, was the first of sixty four viceroys who ruled with almost autocratic power, but scarcely any of whom has left a name in history Don Juan de Acuna (1722–34) is mentioned as having been the only native American among them and Don Juan V G Pacheco (1789 94) had at least the merit of betraying some regard for the social welfare of his subjects Under him a regular police the lighting and draining of towns, and other municipal improvements were introduced

But down to the early years of the present century all emoluments in church and state most of the large plantations, of the mines, and of the commerce of the country, continued to be monopolized by the privileged gachupines, whom the creoles and mestizoes had already begun to regard as aliens Hence the first reactionary movements stimulated by Napoleon s deposition of King Ferdinand and arrest of the viceroy Hurrigaray in 1808 were aimed rather against odious class distinctions and the intolerable oppression of the aliens than against the abstract rights of the Spanish crown The long smouldering spirit of discontent at last broke into open revolt in 1810 at Guanajuato under the leadership of Don Miguel Hidalgo After his defeat and execution in 1811 the struggle was continued by Morelos, who like Hidalgo, was a priest and shared his fate in 1815 But he had already called a national assembly at Chilpanzinco and by this body Mexican independence was for the first time proclaimed in 1813 A guerilla warfare kept the national spirit alive till a fresh stimulus was given to it by the Spanish revolution of 1820 Under the leadership of the 'Liberator Iturbide, Mexican independence was again proclaimed on February 24 1821, and the same year the capital was surrendered by O Donoju, the last of the viceroys But even after the revolt had thus been crowned with success a change of *personnel* rather than of system was contemplated nor was Iturbide proclaimed emperor until the Mexican crown had been declined by a royal prince of Spain

Period of independence

Almost simultaneously with this event the republican standard had been raised by Santa Anna at Vera Cruz (December 1822) Thus the nation had no sooner got rid of foreign rule than it became torn by internal dissension But henceforth the struggle is not so much against the privileged classes as between Conservative and Liberal principles,—the former represented chiefly by the church and the superstitious populace, the latter by the more enlightened but not less unscrupulous sections of the community From both the Indios Bravos, that is about a third of the whole population, hold entirely aloof and take advantage of the public disorders to continue their aggressive warfare against all alike.[1] Events now follow in quick succession, and as many as three hundred successful or abortive revolutions are recorded during the brief but stormy life of Mexican national independence.[2] But amid the confusion of empires, republics, dictatorships, and military usurpations, succeeding each other with bewildering rapidity, the thoughtful student will still detect a steady progress towards the ultimate triumph of those Liberal ideas which lie at the base of true national freedom. A brief tabulated summary of the more salient incidents in this eventful struggle must here suffice:—

---

[1] On the general state of religion in Mexico Bates well remarks — "The educated classes conform to the outward ceremonies and ordinances of the church, while inwardly believing little or nothing of its dogmas The lower grades of society are on the other hand steeped in the most grovelling superstition intensified by many traditional Indian reminiscences This section of the community yield a blind obedience to the clergy notwithstanding the severe laws with which the Government has endeavoured to counteract the influence of the priests Even so recently as 1874 a genuine case of witch burning occurred in Mexico "—*Central America*, p 34

[2] From the Aztec *Gatzopin*, centaur, also known as *Chapetones*

1821–23 Mexican independence acknowledged by Spain; regency under Iturbide, who (1822) is elected hereditary constitutional emperor; in December Santa Anna proclaims the republic in Vera Cruz.

1823–24 Provisional Government; Iturbide abdicates, exiled, withdraws to London, but returning is shot (1824).

1824 First Liberal constitution—"Acta Constitutiva de la Federacion Mexicana," then comprising nineteen states and five territories; first president D. Felix Victoria, known as "Guadalupe Victoria."

1828–30 Contested presidencies of Pedraza, Guerrero, and Bustamente.

1835 Reaction of the church party; constitution of 1824 abolished, the federal states fused in a consolidated republic under Santa Anna as president, but practically dictator.

1836 Texas refusing to submit secedes, defeats and captures Santa Anna.

1837 Santa Anna returning resumes office.

1839 Bravo's brief presidency followed by much anarchy.

1841–44 Santa Anna's first dictatorship with two others.

1844 Constitution restored with Santa Anna president; banished same year, he is succeeded by Canalizo.

1845 Herrera president; disastrous war with United States to recover Texas.

1846 Santa Anna again president.

1848 Treaty of Guadalupe; California and New Mexico ceded to United States.

1853 Santa Anna's second dictatorship; treaty of Mesilla (negotiated by Gadsden) ceding extensive territory to United States and reducing Mexico to its present limits; great financial embarrassment; "Plan of Ayutla," flight of Santa Anna followed by universal chaos.

1855 Provisional Government under President Comonfort.

1856 Constitutional convention; radical reforms; rupture with Spain.

1857 Liberal constitution of March 11, suspended December 1; Comonfort dictator; the reaction supported by the church, large part of the army, and all Conservatives, *opposed at* Vera Cruz by Vice-president Benito Juarez at the head of the "Puros," or advanced Liberals; the "War of Reform" begins and lasts till 1860.

1858–59 In the capital Comonfort is deposed by Zuloaga, who abdicates in favour of Miramon, general of the Conservative forces; but declining the presidency Miramon restores Zuloaga; British legation violated; in Vera Cruz the United States envoy MacLean acknowledges Juarez, who introduces further Liberal measures.

1860 Capitulation of Guadalajara; flight of Miramon from the capital; triumph of the Liberals.

1861 Triumphal entry of Juarez into the capital; further radical reforms; marriage declared a civil contract; celibacy and ecclesiastical tribunals suppressed; confiscation of church property valued at £75,000,000 and over a third of the soil; final separation of church and state; Spain, France, and England urge claims for losses of their subjects resident in Mexico; convention of London; intervention of the allies, who occupy Vera Cruz in December.

1862 England and Spain withdraw, their claims having been settled by negotiation; war continued by France.

1863–64 The capital occupied by the French; Louis Napoleon dreams of a universal fusion of the Latin races; offers the Mexican imperial crown to the Austrian archduke Ferdinand Maximilian, who accepts and arrives in June 1864.

1867 After divers issues the French withdraw; Maximilian, abandoned to his fate, is captured and shot at Queretaro (June 19).

1867–69 Various pronunciamientes by Santa Anna and others.

1871–72 Juarez president; he dies in office July 1872; succeeded by his secretary Lerdo de Tejada.

1873–74 The Liberal constitution of 1857, which had been twice suspended (1858–60 and 1863–67), is now largely amended, and continues to be henceforth the organic law of Mexico.

1876 Tejada succeeded by Porfirio Diaz.

1880 Manuel Gonzalez, reigning president.

Since 1869 the Liberal party has succeeded in preserving peace at home and abroad, while establishing democratic institutions on a firm basis. A. v. Humboldt's gloomy anticipations[3] have not been realized, and for the first time in its chequered history Mexico may look forward with some confidence to a bright future. The plague spot is the uncivilized Indian element. But with boundless natural resources at its disposal, a wise administration may hope to overcome that difficulty, and gradually effect a complete fusion of the antagonistic racial elements.

Literature.—J. Frost, *History of Mexico and its Wars*, with addenda by A. Hawkins, New Orleans, 1882; T. U. Brocklehurst, *Mexico To-day*, London, 1882; Lorenzo Castro, *Mexico in 1882*, New York, 188[illegible]; Aubertin, *A Flight to Mexico*, 1882; E. Busto, *Estadistica de la Republica Mexicana*, Mexico, 1880; Don Lucas Alaman, *Historia de Mexico*, Mexico, 1849–52; J. M. L. Mora, *Mexico y sus Revoluciones*, Paris, 1836; F. K. H. von Richthofen, *Die politischen Zustande der Republik Mexico*, Berlin, 18[illegible]4–59; W. H. Prescott, *History of the Conquest of Mexico*, New York, 1847; E. Muhlenpfordt, *Schilderung der Rep. Mexico besonders in Beziehung auf Geographie, Ethnographie, und Statistik*, Hanover, 1844; A. R. Thummel, *Mexico und die Mexicaner in physischer, socialer, und politischer Beziehung*, Erlangen, 1848; Brantz Mayer, *Mexico as it was and as it is*, New York, [illegible] and *Mexico, Aztec, Spanish, and Republican*, Hartford, 18[illegible]; F. W. [illegible]

[illegible] adelphia, 1846; A. von Humboldt, *Vues des Cordillères et monuments des peuples indigènes de l'Amérique*, Paris, 1810, and *Versuch über den politischen Zustand des Königreichs Neu-Spanien*, Tubingen, 1809–13 (French ed., Paris, 1811); Miguel Lerdo de Tejada, *Comercio exterior de Mexico desde la Conquista hasta hoy*, Mexico, 18[illegible]; John M'Gregor, *States of Mexico* (commercial tariffs, &c.), London, 184[illegible]; *Anales del Ministerio de fomento, colonizacion, industria, y comercio de la Republica Mexicana y repertorio de noticias sobre ciencias, artes, y estadistica nacional y extranjera*, Mexico, 18[illegible]5; *Memoria sobre el estado de la agricultura y industria de la Republica que la direccion general de estos ramos presenta al Gobierno Supremo*, &c., Mexico, 1843–46; Don Mariano Galvez, *Industria Nacional*, Mexico, 1845, and *Estatuto organico de la Republica Mexicana*, Mexico, 1857; H. W. Bates, *Central America*, &c., with ethnological appendix by A. H. Keane, London, 1878; Surveys of the French Corps Expeditionnaire embodied in the *Carte du Mexique*, with accompanying monograph by M. Niox, Paris, 18[illegible]. Other large and more or less trustworthy maps are—A. G. Cubas, *Carta Geografica*, Mexico, 18[illegible]4; *The Library Map of Mexico*, Chicago, 1882; Humboldt, *Atlas Géographique et physique du Royaume de la Nouvelle Espagne*, Paris, 1811; *Mapa de los Estados Unidos de Mexico*, &c., published by J. Disturnell, New York, 1847; Brué, *Carte générale des États Unis Mexicains*, Paris, 18[illegible]; H. Kiepert, *Mexico, Texas, und Californien*, Weimar, 1847; F. de Gerolt y C. de Berghes, *Carta geognostica de los principales distritos minerales del Estado de Mexico formada sobre observaciones astronomicas, barometricas, y mineralogicas*, Mexico, 18[illegible]7; the large physical and geological maps accompanying Von Egloffstein's above quoted work; and a good relief map in F. Ratzel's *Aus Mexico*, Breslau, 1878. (A. H. K.)

III. THE CITY OF MEXICO

Mexico, the capital formerly of the Aztec empire and of the Spanish colony of New Spain, and now of the republic, state, and federal district of Mexico, stands on the Anahuac plateau, 7524 feet above sea level, 2½ miles from the south-west side of Lake Tezcuco (Texcoco), the lowest and largest of six basins filling the deepest depression in the hill encircled Mexican valley. Situated in 19° 25′ 45″ N. lat. and 99° 7′ W. long., it is 173 miles by rail from Vera Cruz on the Atlantic, 290 from Acapulco on the Pacific, 285 from Oajaca, 863 from Matamoros on the United States frontier. Mexico is the largest and finest city in Spanish America, forming a square nearly 3 miles both ways, and laid out with perfect regularity, all its six hundred streets and lanes running at right angles north to south and east to west, and covering within the walls an area of about 10 square miles, with a population (in 1880) of 230,000. Most of the inhabitants are pure blood Indians or mestizoes, but the foreigners, chiefly French, English, Germans, Americans, and Spaniards, monopolize nearly all the trade, and as capitalists, bankers, merchants, and dealers enjoy an influence out of all proportion to their numbers. A large portion of the natives are mendicants or vagrants, and the distinctly criminal element (26,470 in 1878) is kept in order by a police force of 1320 men, yet in that year there were as many as 5370 knife attacks and 3250 robberies. The broad, well paved, and gas lit streets present a picturesque appearance with their quaint two and three storied stone houses gaily painted in white, red, yellow, or green, and terminating everywhere with a background of rugged sierras or snowy peaks which, owing to the bright atmosphere at this elevation, seem quite close, although really 30 or 40 miles distant. All the main thoroughfares converge on the central Plaza de Armas (Plaza Mayor, or Main Square), which covers 14 acres, and is tastefully laid out with shady trees, garden plots, marble fountains, and seats. Here also are grouped most of the public buildings, towering above which is the cathedral, the largest and most sumptuous church in America, which faces the north side of the plaza on the site of the great pyramidal teocalli or temple of Huitzilopochtli, titular god of the Aztecs. This edifice, which was founded in 1573 and finished in 1657, at a cost of £400,000 for the walls alone, forms a Greek cross 426 feet long and 203 wide, with two great naves and three aisles, twenty side chapels, and a magnificent high altar supported by marble columns, and surrounded by a tumbago balustrade with sixty two statues of the same rich gold, silver, and copper alloy serving as candelabra. The elaborately carved choir is also enclosed by tumbago railings made in Macao, weighing 26 tons, and valued at about £300,000. In the interior the Doric style prevails, Renaissance in the exterior, which is adorned by a fine dome and two open towers 218 feet high. At the foot of the left tower is placed the famous calendar stone, the most interesting relic of Aztec culture. The east side of the plaza is occupied by the old viceregal residence, now the National Palace, with 675 feet frontage, containing most of the Government offices (ministerial, cabinet treasury), military headquarters, archives, meteorological department with observatory, and the spacious hall of ambassadors with some remarkable paintings by Miranda and native artists. North of the National Palace, and apparently forming portions of it, are the post office and the national museum of natural history and antiquities, with a priceless collection of Mexican remains. Close to the cathedral stands the Monte de Piedad, or national pawnshop, a useful institution, endowed in 1744 by Terreros with £75,000, and now possessing nearly £2,000,000 of accumulated funds. Facing the cathedral is the Palacio Municipal (city hall) 252 feet by 122, rebuilt in 1792 at a cost of £30,000, and containing the city and district offices, the corporation jail, and the lonja, or merchants' exchange. Around the Plaza San Domingo are grouped the convent of that name, said to contain vast treasures buried within its walls, the old inquisition, now the school of medicine, and the custom house. In the same neighbourhood are the church of the Jesuits and the school of arts, "an immense workshop, including iron and brass foundries, carriage and cart mending, building and masonry, various branches of joinery and upholstery work, and silk and cotton hand weaving (Brocklehurst). Other noteworthy buildings are the national picture gallery of San Carlos, the finest in America, in which the Florentine and Flemish schools are well represented, and which contains the famous Las Casas by Felix Parra, the national library of St Augustine, with over 100,000 volumes, numerous MSS, and many rare old Spanish books, the mint, which since 1690 has issued coinage, chiefly silver, to the amount of nearly £400,000,000, the Iturbide hotel, formerly the residence of the emperor Iturbide, the Mineria, or school of mines, with lecture rooms, laboratories, rich mineralogical and geological specimens, and a fossil horse 3 feet high of the Pleistocene period. Owing to the spongy nature of the soil, the Mineria and many other structures have settled out of the perpendicular, thus often presenting irregular lines and a rickety appearance. Among the twenty scientific institutes mention should be made of the Geographical and Statistical Society, whose meteorological department issues charts and maps of unsurpassed excellence.

---

[1] In December 1882 a party of seventy-five Mexicans and Americans were massacred in the state of Chihuahua by a band of Bravos.

[2] Between 1821 and 1868 the form of government was changed ten times, over fifty persons succeeded each other as presidents, dictators, or emperors; both emperors were shot, Iturbide in 1824, Maximilian in 1867, and according to some calculations there occurred at least three hundred *pronunciamientos*.

[3] Consulted shortly before his death as to the future prospects of Mexico, with which his name was so intimately associated, Humboldt ventured to prophesy that "die Vereinigten Staaten werden es an sich reissen und dann selbst zerfallen."

Besides the chief market south of the National Palace there are three others, all well stocked with meat, fish, and especially vegetables, fruits, and flowers grown mainly on the *chinampas*, or floating gardens of Lakes Chalco and Xochimilco. These gardens, which were far more numerous in the Aztec times, are formed by placing layers of turf on the matted aquatic vegetable growths to a height of 2 or 3 feet above the water and securing them by long willow poles driven through them to the bottom, where they take root. They form plots 100 to 200 feet long by 20 to 100 broad, and are firm enough to support the huts of the cultivators. From the still extant illuminated tribute rolls it appears that the Aztec rulers derived a large share of the taxes from these gardens, which at that time also covered the brackish waters of Lake Tezcuco.

Before 1860 half of the city consisted of churches, convents, and other ecclesiastical structures, most of which have been sequestrated and converted into libraries, stores, warehouses, and even stables, or pulled down for civic improvements. Nevertheless there still remain fourteen parish and thirty other churches, some of large size with towers and domes, and their number has now been increased by six Protestant churches, including the Anglican cathedral in San Francisco Street. This is the leading thoroughfare, and is rivalled in splendour only by the new Cinco de Mayo Street running from the National Theatre to the cathedral.

The city is supplied by two monumental aqueducts from Chapultepec and the south west, with good water at the rate of 44 gallons per day per inhabitant.

Its industries are varied but unimportant, consisting chiefly of gold and silver work, coarse glazed and unglazed pottery of peculiar form and ornamentation, paper, feather work remarkable for its taste and beautiful designs, toys, rosaries, crucifixes, religious pictures, lace, and some weaving.

Mexico enjoys an equable climate with a temperature varying from 70 to 50 F, but rendered unhealthy by the exhalations from the lakes and the bad drainage. The death rate in 1876 was 39 per 1000 and 5 in 1878, pneumonia being most fatal (12 per cent of the total). Standing at the lowest level of a lacustrine valley 1400 square miles in extent and completely encircled by hills with no natural outlet, the city has always been subject to floodings from the overflow of the neighbouring freshwater Lakes Zumpango and Xaltocan on the north and Xochimilco and Chalco on the south, which in the 17th century laid the whole district under water in 1607, and again for five years from 1629 to 1634. To remedy the evil the engineer Martinez began in 160 the great cutting 13 miles long through the Nochistongo hill in order to draw off the discharge of Lake Zumpango, the highest in the valley, to the river Tula, a tributary of the Panuco flowing to the Atlantic. This work, which cost the lives of 70,000 natives, was completed in 1789, but the result was not satisfactory, and the city is still often flooded.

The chief public promenades are the Alameda, planted with stately beeches, the Vega, skirted by the Vega Canal and adorned with the colossal bust of Guatemozin, the last of the Aztec emperors, the Paseo de la Reforma, a fine avenue 3 miles long running south to the famous castle of Chapultepec, a place intimately associated with the names both of Montezuma and Maximilian. The present castle, erected in 1785 by the viceroy Galvez on the site of Montezuma's palace, commands a superb view of the city and sur- [illegible]

Other good roads with horse or steam trams lead to Tacubaya and the Noche Triste tree, where Cortes is traditionally supposed to have rested after the disastrous retreat from Mexico on the night of June 30, 1520, to the pleasant summer suburb of Tacubaya, and to the renowned shrine of Our Lady of Guadalupe, 3 miles to the east on the border of Lake Tezcuco. Here stands the most famous church in Mexico, erected to commemorate the legendary apparitions of the Madonna to the Indian Juan Diego in December 1531, and still visited by thousands of pilgrims or sightseers.

Mexico dates either from the year 1325 or 1327, when the Aztecs after long wanderings over the plateau were directed by the oracle to settle at this spot. For here had been witnessed the auspicious omen of an eagle perched on a nopal (cactus) and devouring a snake. Hence the original name of the city, Tenochtitlan (nopal on a stone), changed afterwards to Mexico in honour of the war god Mexitli. With the progress of Aztec culture the place rapidly improved, and about 1450 the old mud and rush houses were replaced by solid stone structures erected partly on piles amid the islets of Lake Tezcuco, and grouped round the central enclosure of the great teocalli. The city had reached its highest splendour on the arrival of the Spaniards in 1519, when it comprised from 50,000 to 60,000 houses, with perhaps 500,000 inhabitants, and seemed to Cortes "like a thing of fairy creation rather than the work of mortal hands" (Prescott). It was at that time about 12 miles in circumference, every where intersected by canals, and connected with the mainland by six long and solidly constructed causeways, as is clearly shown by the plan given in the edition of Cortes s letters published at Nuremberg in 1524 (reproduced in vol iv of H H Bancroft s *History of the Pacific States* San Francisco 1883 p 280) After its almost total destruction in November 1521 Cortes employed some 400 000 natives in rebuilding it on the same site but since then the lake seems to have considerably subsided, for although still 50 square miles in extent it is very shallow, and has retired 2½ miles from the city During the Spanish rule the chief event was the revolt of 1692 when the municipal buildings were destroyed Since then Mexico has been the scene of many revolutions, and after the battle of Chapultepec (September 13, 1847) the city was held by the United States troops till the treaty of Guadalupe, May 1848 But since the disorders ending with the death of Maximilian it has turned to peaceful ways, and has become a great centre of civilizing influences for the surrounding semi barbarous peoples (A H K)

MEYERBEER, GIACOMO (1791–1863), first known in Germany as Jakob Meyer Beer was born at Berlin on September 5, 1791,[1] of a wealthy and talented Jewish family His father, Herz Beer was a banker, his mother, Amalie (*nee* Wulf) was a woman of high intellectual culture, and two of his brothers distinguished themselves in astronomy and literature He studied the pianoforte, first under Lauska and afterwards under Lauska s master, Clementi When seven years old he played Mozart s Concerto in D Minor in public and at nine he was pronounced the best pianist in Berlin For composition he was placed under Zelter whose lessons were soon exchanged for those of Bernard Weber, then director of the Berlin opera, by whom he was introduced to the Abbe Vogler Struck by his brilliant talent Vogler invited him to Darmstadt, and in 1810 received him into his house, where he formed an intimate friendship with Karl Maria von Weber, who, though his senior by eight years, shared the daily lessons he received from the abbé in counterpoint, fugue, and extempore organ playing At the end of two years the grand duke appointed Meyerbeer composer to the court His early works, however were far from successful —his first opera, *Jephtha s Gelubde*, failing lamentably at Darmstadt in 1811, and his second, *Wirth und Gast* (*Alimelek*) at Vienna in 1814 These checks discouraged him so cruelly that he feared he had mistaken his vocation Nevertheless by advice of Salieri, he determined to study vocalization in Italy and then to form a new style But at Venice he was so captivated by the style of Rossini that renouncing all thought of originality, he produced a succession of seven Italian operas—*Romilda e Costanza*, *Semiramide riconosciuta*, *Edoardo e Cristina*, *Emma di Rosburgo Margherita d Anjou L Esule di Granata*, and *Il Crociato in Egitto*—which all achieved a success as brilliant as it was unexpected Against this act of treason to German art Weber protested most earnestly and before long Meyerbeer himself grew tired of his defection, though the success of *Il Crociato* was so great that he was crowned upon the stage An invitation to Paris in 1826 led him to review his position fairly and dispassionately, and he could not conceal from himself the fact that he was wasting in imitation powers which rightly used might make his name immortal For several years after this he produced nothing in public, but, in concert with Scribe he planned the work which first made known the reality of his transcendent genius—his first French opera, *Robert le Diable* This gorgeous drama was produced at the Grand Opéra in 1831 and received with acclamation It was the first of its race a grand romantic opera abounding with scenes of startling interest, with situations more powerfully dramatic than any that had been attempted either by Cherubini or Rossini with mysterious horrors and chivalric pomp, and with ballet music such as had never yet been heard, even in Paris Its popularity exceeded all previous expectation, yet for five years after this signal triumph Meyerbeer appeared before the public no more We cannot doubt that his motive for this retirement was the determination to produce something greater still, and in some respects his next opera, *Les Huguenots*, really was greater, though it fell short of the deep romance which rendered *Robert le Diable* so incomparably captivating

The first performance of *Les Huguenots* took place in 1836 In gorgeous colouring, in depth of passion, in consistency of dramatic treatment, and in careful delineation of individual character, it is at least the equal of *Robert le Diable* In two points only did its interest fall short of that inspired by the earlier work Meyerbeer had shown himself so great a master in his treatment of the supernatural that one regretted the unavoidable omission of that powerful element in his second grand opera, and, more important still, the fifth act of *Les Huguenots* was so arranged by the librettist as to render effective musical treatment impossible The substitution of a noisy fusillade for a legitimate dramatic situation was fatal to the anticipated climax The music which accompanies this division of the work is necessarily inferior to all that precedes it The true interest of the drama culminates at the close of the fourth act, when Raoul, leaping from the window, leaves Valentine fainting upon the ground The spectator needs not to be told that the former will be shot down the moment he arrives in the street, or that the latter will mourn for him to the end of her days Neither musically nor dramatically does anything more remain to be said, and therefore it is that those who quit the theatre when the curtain falls for the fourth time carry away with them a far more perfect ideal than those who remain to the end

After the production of *Les Huguenots* Meyerbeer again retired from public view, and spent many years in the preparation of two of his greatest works—the greatest of all except the two we have already mentioned—*L Africaine* and *Le Prophete* The libretti of both these operas were furnished by Scribe, and both were subjected to countless changes of detail before they satisfied the composer's fastidious taste, in fact, the story of *L Africaine* was more than once entirely rewritten

Meanwhile Meyerbeer accepted the appointment of kapellmeister to the king of Prussia, and spent some years at Berlin, where he produced *Ein Feldlager in Schlesien*, a German opera, in which the matchless cantatrice Jenny Lind made her first appearance in Prussia, with unprecedented success Here also he composed, in 1846, the overture to his brother Michael s drama, *Struensee* But his chief care at this period was bestowed upon the worthy presentation of the works of others He began by producing his dead friend Weber s *Euryanthe*, with scrupulous attention to the composer s original idea With equal unselfishness he procured the acceptance of *Rienzi* and *Der Fliegende Hollander*, the first two operas of Richard Wagner, who, then languishing in poverty and exile, would, but for him, have found it impossible to obtain a hearing in Berlin With Jenny Lind as prima donna and Meyerbeer as conductor, the opera flourished brilliantly in the Prussian capital, but the anxieties of this thankless period materially shortened the composer s life

Meyerbeer produced *Le Prophete* at Paris in 1849, and, if it did not at first create so great a sensation as *Les Huguenots*, this was simply because it needed to be better known In 1854 he brought out *L Étoile du Nord* at the Opéra Comique, and in 1859 *Le Pardon de Ploermel* (*Dinorah*) His last great work, *L'Africaine*, was in active preparation at the Académie when, on the 23d of April 1863, he was seized with a sudden illness, of which he died on the 2d of May *L Africaine* was produced with pious attention to the composer's minutest wishes, on April 28, 1865, and fully justified the expectation which had been raised by his long and painstaking consideration of its details Upon this, in conjunction with *Robert le Diable*, *Les Huguenots*, and *Le Prophete*, his fame now almost entirely rests

---

[1] Or, according to some accounts, 1794

Meyerbeer's genius has been criticized with widely different results Mendelssohn thought his style exaggerated Fétis thought him one of the most original geniuses of the age Wagner calls him ' a miserable music maker and ' a Jewish banker to whom it occurred to compose operas But the reality of his talent has been recognized throughout all Europe and, in spite of the acknowledged crudity of his system of phrasing and the inequality of merit too plainly observable even in his greatest works his name will live so long as intensity of passion and power of dramatic treatment are regarded as indispensable characteristics of dramatic music (W S R)

MÉZIERES, a fortress of the first class, and the capital of the department of Ardennes, France, is 161 miles to the north east of Paris by railway, on a peninsula of the Meuse, which almost entirely surrounds the town, and separates it from its more important suburb, Charleville The fortifications, which, as well as the citadel, are the work of Vauban, are pierced by four gates, giving access to the town, the streets of which are narrow and winding The parish church, erected in the 16th century, contains two inscriptions in commemoration respectively of the raising of the siege of Mézières in 1521 and the marriage of Charles IX with the daughter of the emperor Maximilian II, which was celebrated at Mézieres in 1570 The north and south portals, the glass of the windows and the lofty vaultings of the church are worthy of remark The hotel de ville contains several interesting pictures relating to the history of the town The iron industry the only one of any importance, is being gradually transferred to Charleville The population in 1881 was 6120

Founded in the 9th century Mézieres was at first only a stronghold belonging to the bishops of Rheims which afterwards became the property of the counts of Rethel The town was increased by successive immigrations of the people of Liége flying first from the emperor Otho and afterwards from Charles the Bold and also by concessions from the counts of Rethel Its walls were built in the 13th century, and in 1521 it was successfully defended by Bayard against the imperialists The anniversary of the deliverance of the town is still observed yearly on the 27th of September The school of military engineering since transferred successively to Metz and Fontainebleau was originally founded at Mézieres

MEZO TUR,[1] a corporate town in the Cis Tisian county of Jász Nagy Kun Szolnok Hungary, situated on the right bank of the Berettyo, and on the railway from Arad to Szolnok, in 47° 1 N lat, 20 39 E long It has Roman Catholic and Calvinist churches and schools, a judicial court for the circuit, and the usual Government offices, but can boast of few buildings of special interest Horses oxen, and sheep are reared in great numbers on the wide spreading communal lands, which are productive also of cereals, and especially wheat, rape seed, and maize On the 31st December 1880 the population amounted to 20,649 (10,265 males, 10,384 females) mostly Magyars by nationality

MEZZOFANTI, GIUSEPPE (1774–1849), cardinal whose colloquial linguistic acquirements have become proverbial, was born, September 17, 1774 at Bologna, where his father followed the occupation of a carpenter Educated first at one of the "scuole pie, and afterwards at the episcopal seminary of his native city, he was ordained to the priesthood in 1797, and in the same year became professor of Arabic in the university, but shortly afterwards was deprived on account of his refusal to take the oath of allegiance to the Government of the Cisalpine Republic In 1803, however, he was appointed assistant librarian of the institute of Bologna and soon afterwards was reinstated as professor of Oriental languages and of Greek The chair was suppressed by the viceroy in 1808, but again rehabilitated on the restoration of Pius VII in 1814, and continued to be held by Mezzofanti until his removal from Bologna to Rome in 1831, when he received certain ecclesiastical appointments and the rank of monsignore Meanwhile his progress in the acquirement of languages had been rapid and untiring, and in 1833 he was appointed to succeed Mai as chief keeper of the Vatican Library His promotion to the cardinalate, and the duties of director of studies in the Congregation of the Propaganda, followed in 1838 He died at Rome, during the absence of the pontifical court at Gaeta, on March 15, 1849

Mezzofanti's peculiar talent comparable in many respects to that of the numerous ' calculating boys who have been the wonder of their contemporaries was not combined with any exceptional measure of intellectual power and accordingly produced nothing that has not perished with him It seems to be well established, however that he spoke with considerable fluency and in some cases even with attention to dialectic peculiarities some fifty or sixty languages of the most widely separated families, besides having a less perfect acquaintance with many others See Manavit *Esquisse historique sur le Cardinal Mezzofanti* Paris 1854 and Russell, *Life of the Cardinal Mezzofanti* London 1857

MEZZOTINT See ENGRAVING

MIAUTSE The Miautse or Meaou tsze of southern China are one of the aboriginal tribes of the country At one time they occupied a considerable portion of the rich and fertile lands which now form the central province of the empire but as the Chinese advanced southwards they were driven like the Ainos in Japan and the Welsh in Britain into the more inaccessible districts until they were compelled to seek refuge from the invaders in the mountain ranges, in the provinces of Yunnan, Kweichow, Kwangse, and Kwangtung, where they are found at the present day This line of mountains extends for about 400 miles, and, being in many parts high, steep, and rugged, it forms a convenient shelter for them As early as the reign of king Seuen (about 800 B C) we read of an expedition having been sent to drive them out of Hoo-nan, and since that time they have been periodically attacked either to punish them for misdeeds or to make them yield up vineyards coveted by Chinese Ahabs The last important campaign against them was undertaken by the emperor Keen lung, who, having completely subjugated the Eleuths, was desirous of bringing under his yoke these mountain tribesmen But the same success which had attended his arms in the north did not follow them to the south The first expedition was utterly defeated and the general in command paid the penalty of discomfiture with his head The leader of a second expedition, having learned wisdom by the fate of his predecessor, purchased the submission of the Miautse by a large bribe As soon as the unsuspecting savages had been thus lulled into security a third army was set in motion against them This time, being unprepared, they suffered a crushing defeat, and were compelled to purchase peace by swearing allegiance to their conquerors But, though the Chinese thus gained sovereignty over them, they have since deemed it wise to content themselves with but the shadow of authority No real jurisdiction is ever exercised over these hardy mountaineers They are allowed to govern themselves on their own patriarchal system The old men of each tribe manage the affairs of their juniors, and command an obedience which would be utterly refused to the mandate of any mandarin In figure the Miautse, both men and women, are shorter and darker complexioned than the Chinese, their faces also are rounder and their features sharper In disposition, too, they are very unlike their civilized neighbours They are brave, passionate, suspicious, revengeful, and indifferent to cold and hunger, they are free and easy in their manners, and are as noisily joyous as the Chinese are grave and sedate

---

[1] Mezo is a Magyar word, signifying *Field*, prefixed to many agricultural localities in Hungary

They are divided into between forty and fifty clans, each of which is distinguished by a name which is generally derived either from some physical characteristic, or from some custom, or from the habitat of the clan, as, for example, "The Black Miau" "the narrow headed Miau," so named from their manner of dressing their hair, "the six valley Miau" &c Among these clans there exist wide differences of culture some being in no way removed from savages, while others who have been brought under the influence of Chinese civilization show themselves apt and ready learners Very few of them so far as is known, possess any written records The Yaou jin, or Goblin clan are said to have books which, though they are now unable to read they still regard with reverent awe "The barbarous characters used in these books are according to a Chinese writer like knotted worms and are utterly unintelligible The Ko los also are said to be a lettered clan but for the most part the Miautse content themselves with conveying information and preserving records by means of notched sticks Their language as well as their their characteristics prove them to be closely related to the Siamese Anamese, Cambodians and the inhabitants of Hainan, in fact they form part of the race which is spread over the whole of south eastern Indo China Their social customs are as widely different as their appearance is from those of the Chinese The widest latitude is given to the youth of both sexes in the choice of their husbands and wives As among the hill tribes of Chittagong, the selection is commonly made on the mountain side, where on moonlight nights in the "leaping month" the young men and maidens meet to sing or to play at ball or to dance round the "devil's staff" (*Anglice* May pole), and to choose their partners for life Among some clans the "couvade" is an established custom Their funeral rites vary according to the districts those living within reach of the influence of the Chinese having adopted their customs, while those more remote still hang their dead in baskets from trees or lay them in the ground and disinter them yearly to wash their bones In dress they are fond of bright colours, and commonly wear loose but short jackets sometimes with and sometimes without trousers The men wear turbans wound round their hair which is raised above the head in the shape of a spiral shell and the women either don a kind of cap or dress their hair in the shape of a ram's horn For many years the relations of the Miautse with the Chinese Government have been generally of a peaceable nature, and in the *Peking Gazette* of April 1881 there was published a new system of government by which it is hoped that the incorporation of the mountaineers into the empire may become more real and complete

See *Sketches of the Miau tse* translated by Rev C Bridgman J Edkins *The Miau tsi Tribes their History*, and "Quaint customs in Kweichow" *Cornhill Magazine* January 187

MICAH (מִיכָה) is the short form of a name which in various modifications—*Micaiahu*, *Micaiehu*, *Micaiah*—is common in the Old Testament, expressing as it does a fundamental point of Hebrew faith Who is like Jehovah? The name was borne among others by the Danite whose history is given in Judg xvii *sq*, by the prophet who opposed Ahab's expedition to Ramoth Gilead (1 Kings xxii), and by the subject of the present article, the contemporary and fellow worker of Isaiah, whose name is prefixed to the sixth in order of the books of the minor prophets [1]

It is at once apparent that the book of Micah divides itself into at least two distinct discourses, chap vi 1 forming a new commencement, and from what we know in general of the compilation of the prophetic collection we cannot at once determine whether the second discourse, which has no title, is to be ascribed to the author of the immediately preceding prophecy, or is to be regarded as an independent and anonymous piece To decide this question, if it can be decided, we must begin by a separate study of the earlier chapters to which the title in Micah i 1 directly belongs. These again fall into two parts Chaps i–iii (with the exception of two verses, ii 12, 13) are a prediction of judgment on the sins of Judah and Ephraim. In a majestic exordium Jehovah Himself is represented as coming forth in the thunderstorm (comp Amos i 2) from His heavenly palace, and descending on the mountains of Palestine, at once as witness against His people, and the executer of judgment on their sins. Samaria is sentenced to destruction for idolatry, and the blow extends to Judah also, which participates in the same guilt (chap i) But, while Samaria is summarily dismissed, the sin of Judah is analysed at length in chaps ii and iii, in which the prophet no longer deals with idolatry, but with the corruption of society, and particularly of its leaders—the grasping aristocracy whose whole energies are concentrated on devouring the poor and depriving them of their little holdings, the unjust judges and priests who for gain wrest the law in favour of the rich, the hireling and gluttonous prophets who make war against every one "that putteth not into their mouth," but are ever ready with assurances of Jehovah's favour to their patrons, the wealthy and noble sinners that fatten on the flesh of the poor The prophet speaks with the strongest personal sympathy of the sufferings of the peasantry at the hands of their lords, and contemplates with stern satisfaction the approach of the destroyer who shall carry into exile "the luxurious sons" of this race of petty tyrants (i 16), and leave them none to stretch the measuring line on a field in the congregation of Jehovah (ii 5) The centre of corruption is the capital, the city of Zion, grown great on the blood and wrongs of the provincials, the seat of the cruel princes, the corrupt judges and diviners For their sake, he concludes, Zion shall be plowed as a field, Jerusalem shall lie in ruins, and the temple hill return to jungle (iii 12)

The situation thus sketched receives its elucidation from the data supplied by the title (i 1) and confirmed and rendered more precise by a remarkable passage in Jeremiah. According to the title Micah flourished in the reigns of Jotham, Ahaz, and Hezekiah, according to Jeremiah (xxvi 18 *sq*) the prophecy of the destruction of Jerusalem just cited was spoken under Hezekiah, and bore fruit in the repentance of king and people, by which the judgment was averted The allusion beyond doubt is to Hezekiah's work of religious reformation (2 Kings xviii 4 *sq*) It is hardly possible to separate this reformation from the influence of Isaiah, which did not become practical in the conduct of the state till the crisis of Sennacherib's invasion, and the conclusion that Hezekiah was not from the first a reforming king, which is forced on us by many passages of Isaiah, is confirmed by the prophecy of Micah, which, after Hezekiah's accession, still represents wickedness as seated in the high places of the kingdom The internal disorders of the realm depicted by Micah are also prominent in Isaiah's prophecies, they were closely connected, not only with the foreign complications due to the approach of the Assyrians, but with the break up of the old agrarian system within Israel, and with the rapid and uncompensated aggrandisement of the nobles during those prosperous years when the conquest of Edom by Amaziah and the occupation of the port of Elath by his son (2 Kings xiv 7, 22) placed the lucrative trade between the Mediterranean and the Red Sea in the hands of the rulers of Judah On the other hand the democratic tone which distinguishes Micah from Isaiah, and his announcement of the *impending fall of the capital* (the deliverance of which from the Assyrian appears to Isaiah as the necessary condition for the preservation of the seed of a new and better kingdom), are explained by the fact that, while Isaiah lived in the centre of affairs, Micah was a Morasthite or inhabitant of Moresheth Gath, a place near the Philistine frontier so unimportant as to be mentioned only in Micah i. 14.[1] The provincial prophet sees the capital and the aristocracy entirely from the side of a man of the oppressed people, and foretells the utter ruin of both. But this ruin does not present itself to him as involving the captivity or ruin of the nation as a whole; the congregation of Jehovah remains in Judæa when the oppressors are cast out (ii. 5), Jehovah's words are still good to them that walk uprightly, the glory of Israel is driven to take refuge in Adullam, as in the days when David's band of broken men was the true hope of the nation, but there is no hint that it is banished from the land. Thus upon the prophecy of judgment we naturally expect to follow a prophecy of the redintegration of Jehovah's kingship in a better Israel, and this we find in ii. 12, 13 and in chaps. iv., v. Both passages, however, present difficulties. The former seems to break the pointed contrast between ii. 11 and iii. 1, and is therefore regarded by Ewald as an example of the false prophecies on which the wicked rulers trusted. The thought, however, is one proper to all true prophecy (comp. Hos. i. 11 [ii. 2], Isa. xi. 11 sq., Zeph. iii. 14, Jer. xxxi. 8), and precisely in accordance with chaps. iv., v., even in the details of expression and imagery.[2] It is indeed possible that these verses are a separate oracle of Micah, which did not originally stand in its present connexion. The sequence of thought in chaps. iv., v., on the other hand, is really difficult, and has given rise to much complicated discussion.[3] There is a growing feeling among scholars that iv. 11-13 stands in direct contradiction to iv. 9, 10, and indeed to iii. 12. The last two passages agree in speaking of the capture of Jerusalem, the first declares Zion inviolable, and its capture an impossible profanation. Such a thought can hardly be Micah's, even if we resort to the violent harmonistic process of imagining that two quite distinct sieges, separated by a renewal of the theocracy, are spoken of in consecutive verses. An interpolation, however, in the spirit of such passages as Ezek. xxxviii., xxxix., Joel iii. [iv.], Zech. xiv., is very conceivable in post-exilic times, and in connexion with the growing impulse to seek a literal harmony of all prophecy on lines very different from the pre-exilic view in Jer. xxvi., that predictions of evil may be averted by repentance. Another difficulty lies in the words "and thou shalt come even to Babylon" in iv. 10. Micah unquestionably looked for the destruction of Jerusalem as well as of Samaria in the near future and by the Assyrians (i. 9), and this was the judgment which Hezekiah's repentance averted. If these words, therefore, belong to the original context, they mark it as not from Micah's hand; but it is easy to see that they are really a later gloss. The prophetic thought is that the daughter (population) of Zion shall not be saved by her present rulers or defensive strength; she must come down from her bulwarks and dwell in the open field; there, and not within her proud ramparts, Jehovah will grant deliverance from her enemies. This thought is in precise harmony with chaps. i.-iii., and equally characteristic is what follows in chap. v. Micah's opposition to present tyranny expresses itself in recurrence to the old popular ideal of the first simple Davidic kingdom (iv. 8) to which he had already alluded in i. 15. These old days shall return once more. Again guerilla bands (בת־גדוד) gather to meet the foe as they did in the time of Philistine oppression. A new David, like him whose exploits in the district of Micah's home were still in the mouths of the common people, goes forth from Bethlehem to feed the flock in the strength of Jehovah. The kindred Hebrew nations are once more united to their brethren of Israel (comp. Amos ix. 12, Isa. xvi. 1 sq.). The remnant of Jacob springs up in fresh vigour, inspiring terror among the surrounding peoples, and there is no lack of chosen captains to lead them to victory against the Assyrian foe. In the rejuvenescence of the nation the old stays of that oppressive kingship which began with Solomon, the strong holds, the fortified cities, the chariots and horses so foreign to the life of ancient Israel, are no more known; they disappear together with the divinations, the soothsayers, the idols, the *maççebôs* and *asherás* of the high places. Jehovah is king on Mount Zion, and no inventions of man come between Him and His people.

---

[1] A confusion between the two prophets of the name has led to the insertion in the Massoretic text of 1 Kings xxii 28 of a citation from Micah i. 2, rightly absent from the LXX

The elements of this picture, drawn so largely from the most cherished memories of the Judæans, could not fail to produce a wide impression, especially when the invasion of Sennacherib, although it spared Jerusalem, fulfilled in the most striking way a great part of Micah's predictions of judgment. Of this we have evidence, not only in Jer. xxvi., but in the political and religious ideas of the book of Deuteronomy. The picture of the right king (Deut. xvii. 14 *sq.*) and the condemnation of the high places alike follow the doctrine of Micah.

A difficulty still remains in the opening verses of chap. iv. Micah iv. 1-3 and Isa. ii. 2-4 are but slightly modified recensions of the same text, and as Isa. ii. is older than the prophecy of Micah, while on the other hand Micah iv. 4 seems the natural completion of the passage, it is common to suppose that both copy an older prophet. But the words have little connexion with the context in Isaiah, and may be the quotation of a copyist suggested by ver. 5. On the other hand it has been urged that the passage belongs to a later stage of prophetic thought than the 8th century B.C. There is, however, no real difficulty in the idea that foreign nations shall seek law and arbitrament at the throne of the king of Zion (comp. the old prophecy Isa. xvi. 5), and the mention of the temple as the seat of Jehovah's sovereignty may be illustrated by Isa. vi., where the heavenly palace (Micah i. 3) is at least pictured in the likeness of the temple on Zion. At the same time the Jerusalem of Micah iv. 8 is the Jerusalem of David, not of Solomon; the ideas of iv. 1-4 do not reappear in chap. v., and the whole prophecy would perhaps be more consecutive and homogeneous if iv. 6 (where the dispersed and the suffering are, according to chap. ii., the victims of domestic not of foreign oppression) followed directly on iii. 12.

The sixth chapter of Micah presents a very different situation from chaps. i.-v. Jehovah appears to plead with his people for their sins; but the sinners are no longer a careless and oppressive aristocracy buoyed up by deceptive assurances of Jehovah's help by prophecies of wine and strong drink; they are bowed down by a religion of terror, wearied with attempts to propitiate an angry God by countless offerings, and even by the sacrifice of the first-born. Meantime the substance of true religion—justice, charity, and a humble walk with God—is forgotten; fraud and deceit reign in all classes; the works of the house of Ahab are observed (worship of foreign gods). Jehovah's judgments are multiplied against the land, and the issue can be nothing else than its total desolation. All these marks fit exactly the evil times of Manasseh as described in 2 Kings xxi Chap vii 1-6 in which the public and private corruption of a hopeless age is bitterly bewailed obviously belongs to the same context (comp vol xiii p 41?) Micah may very well have lived into Manasseh's reign but the title in i 1 does not cover a prophecy which certainly falls after Hezekiah's death, and the style has nothing in common with the earlier part of the book It is therefore prudent to regard the prophecy, with Ewald, as anonymous Ewald ascribes the whole of chaps vi, vii to one author Wellhausen however remarks with justice that the thread is abruptly broken at vii 6 and that verses 7-20 represent *Zion* as already fallen before the heathen and her inhabitants as pining in the darkness of captivity The hope of Zion is in future restoration after she has patiently borne the chastisement of her sins Then Jehovah shall arise mindful of His oath to the fathers, Israel shall be forgiven and restored, and the heathen humbled The faith and hope which breathe in this passage have the closest affinities with the book of Lamentations and Isa xl-lxvi

---

[1] That Micah lived in the Shephela or Judæan lowland near the Philistine country is clear from the local colouring of i. 10 *sq.*, where a number of places in this quarter are mentioned together and their names played upon in a way that could hardly have suggested itself to any but a man of the district. The paronomasia makes the verses difficult, and in i. 14 none of the ancient versions recognizes Moresheth Gath as a proper name. The word Morasthite (*Mōrashtī*) was therefore obscure to them, but this only gives greater weight to the traditional pronunciation with *ō* in the first syllable, which is as old as the LXX., and goes against the view, taken by the Targum both on Micah and on Jeremiah, and followed by some moderns (including Roorda), that Micah came from Mareshah. When Eusebius places **Μωρασθεί** near Eleutheropolis it is not likely that he is thinking of Mareshah (Maresa), for he speaks of the former as a village and of the latter as a ruin 2 miles from Eleutheropolis. Jerome too in the *Epit. Paulæ* (*Ep.* cviii.), speaking as an eye-witness, distinguishes Morasthim, with the church of Micah's sepulchre, from Maresa. This indeed was after the pretended miraculous discovery of the relics of Micah in 385 A.D., but the name of the village which then existed (*Præf. in Mich.*) can hardly have been part of a pious fraud.

[2] The figure of the shepherd gathering a scattered flock certainly does not presuppose a total captivity, as Stade (*Z. f. A. T. W.*, i. 161 *sq.*) argues.

[3] See, besides the commentaries, Nöldeke in the *Bibel-lex.*, iv. 214; a paper by Oort and two by Kuenen in *Theol. Tijdsch.*, 1872; Wellhausen-Bleek, *Einleitung*, p. 426; Stade, *l. c.*, and *ibid.*, iii. 1 *sq.* Stade goes so far as to make the whole of Micah iv., v. presuppose the exile, and to find still later additions in iv. 5-10, v. 5, 6 [v. 4, 5]. Giesebrecht, *Theol. LZ.*, 1881, col. 443 *sq.*, rejects chap. iv. only. The arguments cannot be here cited at length, but they are tacitly kept in view in what follows.

We have seen that the text of Micah has suffered from redactors It is also not free from verbal corruptions which make some places very obscure The LXX had many readings different from the present Hebrew but their text too was far from sound Of commentaries on Micah that which deals most fully with the question of the text is Roorda's Latin work Leyden 1869 The most elaborate book on Micah is Caspari's (*Ueber Micha den Morasthiten und seine prophetische Schrift* Christiania 1851) In English Pocock's *Commentary* (2d ed 1692) and Cheyne's *Micah* (1882) are to be noted See also the literature on the mino[illegible]

prophe[illegible] (1882) (W R S)

MICHAEL (מִיכָאֵל, "who is like God?") appears in the Old Testament as a man's name, synonymous with Micaiah or Micah In the book of Daniel the same name is given to one of the chief "princes" of the heavenly host, the guardian angel or "prince" of Israel (Dan x 13, 21, xii 1), and as such he naturally appears in Jewish theosophy as the greatest of all angels, the first of the four who surround the throne of God (see GABRIEL) It is as guardian angel of Israel, or of the church, the true Israel, that Michael appears in Jude 9 and Rev xii 7 In the Western Church the festival of St Michael and All Angels (Michaelmas) is celebrated on September 29th, it appears to have grown out of a local celebration of the dedication of a church of St Michael either at Mount Garganus in Apulia or at Rome, and was a great day by the beginning of the 9th century The Greek Church dedicates November 8 to St Michael, St Gabriel, and All Angels

MICHAEL, the name of several Byzantine emperors

MICHAEL I (Rhangabe) was an obscure nobleman who had married Procopia, the daughter of Nicephorus I, and been made master of the palace, his elevation to the throne was due to a revolutionary movement against his brother in law Stauracius, who reigned only two months after the death of Nicephorus on the battlefield (812) Elected as the tool of the bigoted orthodox party in the church, Michael diligently persecuted the Iconoclasts on the northern and eastern frontiers of the empire, but meanwhile allowed the Bulgarians to ravage a great part of Macedonia and Thrace, having at last taken the field in the spring of 813, he was defeated near Bersinikia, and Leo the Armenian was saluted emperor in his stead in the following summer Michael, after having been compelled to become a monk, was permitted thenceforward to live unmolested in the island of Prote, where he died in 845

MICHAEL II (The Stammerer), a native of Amorium in Phrygia, was of humble origin, and began life as a private soldier but rose by his talents and assiduity to the rank of general He was one of those who had favoured the election to the throne of his old companion in arms Leo the Armenian in 813, but, detected in a conspiracy against the government of that emperor had been sentenced to death in December 820 his partisans, however succeeded in assassinating Leo on the morning of Christmas Day, and called Michael from the prison to the throne The principal features of his reign (820-829) were a protracted struggle (of nearly three years) against his brother general, Thomas, who aimed at the throne the conquest of Crete by the Saracens in 823 and the beginning of their attacks upon Sicily (827) Conciliatory on the whole in his policy towards the image worshippers (his own sympathies were iconoclastic), he incurred the wrath of the monks by entering into a second marriage with Euphrosyne, daughter of Constantine VI, who had previously taken the veil He died in October 829, and was succeeded by Theophilus his son

MICHAEL III (The Drunkard) was the grandson of Michael the Stammerer, and succeeded his father Theophilus when only three years of age (842) Until his majority at the age of eighteen the affairs of the empire were managed by the empress regent his mother Theodora, his education was shamefully neglected, and it was during this period that Michael formed the disgraceful personal habits which are indicated by his surname In 861 Michael, together with his uncle Bardas, undertook an expedition against the Bulgarians, which resulted in the conversion of the Bulgarian king, who thenceforth bore the Christian name of Michael The emperor had been less successful in the campaign which he led in person against Omar of Melitene in 860, but in 863 his uncle Petronas gained an important victory over the Saracens in Asia Minor The year 865 was marked by the first appearance of the Russians in the Bosphorus Michael was assassinated in his palace in 867 by Basilius the Macedonian, whom he had associated with himself in the empire in the previous year

MICHAEL IV (The Paphlagonian) owed his elevation to Zoe, daughter of Constantine IX, the last of the Macedonian dynasty, this princess was married to Romanus III, but becoming enamoured of Michael, her chamberlain, she poisoned her husband and married her attendant (1034) Michael, however, being of a weak character and subject to epileptic fits, possessed the supreme power only in name, and was a mere instrument in the hands of his brother, John the Eunuch, who had been first minister both of Constantine and Romanus John's diplomacy was successful in keeping the Arabs in the archipelago and Egypt quiet for some time, and he was at last able to secure a victory for the imperial arms at Edessa in 1037 The attempt to recover Sicily in the following year with the help of the Normans was less prosperous, and in 1040 the island wholly ceased to be a Byzantine province About the same time, the Bulgarians having overrun Macedonia and Thrace, and threatening Constantinople, the indolent and infirm emperor, to the surprise alike of friends and foes, put himself at the head of the army, and not only drove the enemy beyond the frontier, but followed them into their own territory He died, shortly after his triumph, on December 10, 1041

MICHAEL V (Calaphates or The Caulker), nephew and successor of the preceding, derived his surname from his father Stephen, who had originally followed the occupation of a caulker of ships He owed his elevation (December 1041) to his uncle John, whom along with Zoe he almost immediately banished, this led to a popular tumult and his dethronement after a brief reign of four months (April 1042) He lived for many years afterwards in the quiet obscurity of a monastery

MICHAEL VI (The Warlike) was already an old man when chosen by the empress Theodora as her successor shortly before her death in 1056 His government was feeble in the extreme, and he was at last compelled to abdicate by Isaac Comnenus, who had defeated his army in Phrygia (August 1057) He also spent the rest of his life in a monastery

MICHAEL VII (Ducas or Parapinaces) was the eldest son of Constantine XI Ducas, by whom along with his brothers Andronicus I and Constantine XII he was invested with the title of Augustus this joint succession took place in 1067, but in 1071 it suited the policy of the uncle Joannes Cæsar to make Michael sole emperor For this position Michael, whose "character was degraded, rather than ennobled, by the virtues of a monk and the learning of a sophist," was by no means fitted, and at length two generals of the name of Nicephorus, surnamed Bryennius and Botaniates, simultaneously rebelled against him in 1078; with hardly a struggle he resigned the purple and retired into a monastery, where he afterwards received the title of archbishop of Ephesus.

MICHAEL VIII (Palæologus), born in 1234, was the son of Andronicus Palæologus Comnenus and Irene Angela the granddaughter of Alexius Angelus, emperor of Constantinople. At an early age he rose to distinction, and ultimately became commander of the French mercenaries in the employment of the emperors of Nicæa. A few days after the death of Theodore Lascaris II in 1259, Michael, by the assassination of Muzalon (which he is believed but not proved to have encouraged), succeeded to the guardianship, shared with the patriarch Arsenius, of the young emperor John Lascaris, then a lad of only eight years. Afterwards invested with the title of "despot," he was finally proclaimed joint emperor, and crowned alone at Nicæa on January 1, 1260. In the following year (July 1261) Constantinople fell into the hands of the Cæsar Alexius Strategopulus, and Michael, having got himself crowned anew in the church of St Sophia, caused his boy colleague to be blinded and sent into banishment. For this last act he was excommunicated by Arsenius, and the ban was not removed until six years afterwards (1268), on the accession of a new patriarch. In 1263 and 1264 respectively Michael, with the help of Urban IV, concluded peace with Villehardouin, prince of Achaia, and Michael, despot of Epirus, who had previously been incited by the pope to attack him; the friendly intervention had been secured by a promise on the emperor's part to help forward the reunion of the Eastern and Western churches. In 1269 Charles of Sicily aided by John of Thessaly, again made war with the alleged purpose of restoring Baldwin to the throne of Constantinople, and pressed Michael so hard that ultimately, yielding to the importunities of Gregory X, he caused the deputies of the Eastern church to attend the council of Lyons (1274) and there accept the "filioque" and papal supremacy. The union thus brought about between the two churches was, however, extremely distasteful to the Greeks, and the persecution of his "schismatic" subjects to which the emperor was compelled to resort weakened his power so much that Martin IV was tempted to enter into alliance with Charles of Anjou and the Venetians for the purpose of reconquering Constantinople. The invasion, however, failed, and Michael so far had his revenge in the "Sicilian Vespers," which he helped to bring about. He died in Thrace in December 1282, and was succeeded by his son Andronicus II.

MICHAEL IX (Palæologus) was the son of Andronicus II, and was associated with him on the throne from 1295, but predeceased him (1320).

MICHAELIS, JOHANN DAVID (1717-1791), one of the most influential scholars and teachers of last century, belonged to a family which had the chief part in maintaining that solid discipline in Hebrew and the cognate languages which distinguished the university of Halle in the period of Pietism. Johann Heinrich Michaelis (1668-1738) was the chief director of Francke's *Collegium Orientale Theologicum*, a practical school of Biblical and Oriental philology then quite unique, and the author of an annotated Hebrew Bible and various exegetical works of reputation, especially the *Adnotationes uberiores in Hagiographos*, 1720. In his chief publications J. H. Michaelis had as fellow worker his sister's son Christian Benedict Michaelis (1680-1764), the father of Johann David, who was likewise influential as professor at Halle, and a very sound scholar, especially in Syriac. J. D. Michaelis was trained for academical life under his father's eye. Halle was not then the best of universities; a narrow theological spirit cramped all intellectual activity, and the eager vivacious youth, already distinguished by a love for realities and a distaste for small pedantries, found much of the teaching wearisome enough. He acquired, however, a good knowledge of the Latin classics,—Greek, he tells us, was hardly taught at all, and his knowledge of Greek literature was gained by his own reading in later years,—learned all that his father could teach, and was influenced, especially in philosophy, by Baumgarten, the link between the old Pietism and Semler, while he cultivated his strong taste for history under Ludwig. In the winter semester 1739-40 he qualified as university lecturer. One of his dissertations was a defence of the antiquity and divine authority of the vowel points in Hebrew. His scholarship still moved in the old traditional lines in which no further progress was possible, and he was also much exercised by religious scruples, the conflict of an independent mind with that submission to authority at the expense of reason encouraged by the type of Lutheranism in which he had been trained. A long visit to England in 1741-42 lifted him out of the narrow groove of his earlier education. In passing through Holland he made the acquaintance of the great Schultens, whose influence on his philological views was not immediate but became all powerful a few years later. England offered to him no such commanding personal influence and he was not yet able to turn to profit the stores of the great libraries, but his personality was strengthened by contact with a larger life and his theological views were turned aside from the pietistic channel. Michaelis never ceased to regard himself as essentially orthodox, though he did not feel able fully to subscribe the Lutheran articles and more than once declined on this account to be professor of theology. But his views acquired a distinctly rationalistic complexion, and the orthodoxy of his Göttingen lectures and publications on dogmatic (delivered from a philosophical chair) is of a very washed out kind. His really useful work, however, lay in other directions; the change of his theological views was important because it relieved him from trammels that hampered the free course of his development as a scholar. From England Michaelis went back to Halle, but he felt himself out of place, and in 1745 gladly accepted an invitation to Göttingen as privat docent. In 1746 he became extraordinary, in 1750 ordinary, professor, and in Göttingen he remained till his death in 1791. In the first years of his new position Michaelis passed through a second education. In the young and intellectually vigorous Georgia Augusta he came under the powerful personal influence of such men as Gesner and Haller. His intellect was active in many directions; universal learning indeed was perhaps one of his foibles. Literature—modern as well as ancient—occupied his attention; one of his works was a translation of four parts of *Clarissa*, and translations of some of the then current English paraphrases on Biblical books manifested his sympathy with a school which, if not very learned, attracted him by its freer air. His Oriental studies were reshaped by diligent perusal of the works of Schultens, for the Halle school with all its learning had no conception of the principles on which a fruitful connexion between Biblical and Oriental learning can be established. His linguistic work indeed was always hampered by the lack of MS. material, which is felt in his philological writings, *e.g.* in his valuable *Supplementa* to the Hebrew lexicons (1784-92).[1] He could not become such an Arabist as Reiske, and, though for many years the most famous teacher of Semitic languages in Europe, he had little of the higher philological faculty, and neither his grammatical nor his critical work, highly praised as it then was, has left a permanent mark, with the exception perhaps of his text-critical studies on the Peshito.[1] His tastes were all for *realia*—history, antiquities, especially geography and natural science; in his autobiography he half regrets that he did not choose the medical profession. Here he found a field hardly touched since Bochart, in whose footsteps he followed in the *Spicilegium geographiæ Hebræorum exteræ post Bochartum* (1769-80). To his impulse we owe the famous Eastern expedition of Von Haven, Forskål, and Niebuhr. He prepared the instructions for their journey, and drew up a series of questions and elucidations to guide their researches, which place in strong relief his comprehensive grasp of all that was then known of the East, and the keen delight in the knowledge of tangible and natural things, paired with a sober and patient judgment, which was his chief intellectual characteristic. The best part of this knowledge was turned to the profit of Biblical study; in his exegetical writings for example, one of the main features is what was then the novelty of illustrations from Eastern travel. In spite of his doctrinal writings—which at the time made no little noise, so that his *Compendium of Dogmatic* (1760) was confiscated in Sweden, and the knighthood of the North Star was afterwards given him in reparation—it was the natural side of the Bible that really attracted him, and no man did more to introduce the modern method of studying Hebrew antiquity as an integral part of ancient Eastern life. The permanent influence of his works indeed has not been great, and many of them are now hardly readable; for, with all his historic tastes and learning, he had no large historic conceptions, and, what is closely akin to this defect, was singularly deficient in imagination and poetic sympathy. But the vivacity of his mind, his many-sidedness, his singularly attractive though discursive method of lecturing, and above all his power of feeling and inspiring interest in every kind of fact, was a potent stimulus much needed in the Germany of that age, and did not soon die. Different as the three men are, there is a true historic nexus between the three great Göttingen Orientalists, Michaelis, Eichhorn, and Ewald.

---

[1] [illegible] fortune [illegible] was at [illegible] the occupation of Göttingen by the French in the Seven Years War and the friendly relations he

The personal character of Michaelis can be read between the lines of his autobiography with the aid of the other materials collected by the editor Hassencamp (*J. D. Michaelis Lebensbeschreibung*, &c., 1793). To understand the secret of his enormous influence it is not enough to read his books, now for the most part dull enough to us; we must see the upright vivacious laborious man, with a good deal of worldly prudence and a good deal of temper, much absorbed in his manifold academic activities in the university and Royal Society of Göttingen, yet ever full of interest in the larger world, and of shrewd judgments and lively talk, with a strong sense of his rights and dignity, yet with a good and warm heart; shining especially in the lecture room, where he dealt forth knowledge with discursive hand from a full store, displaying the methods as well as the results of his all-sided research, not without a touch of the vanity of the polyhistor, and loving to leave the chair under a storm of applause at a parting bon mot which he acknowledged at the door in a backward glance of triumph. The same volume contains a full list of his works. Besides those already mentioned it is sufficient to refer to his New Testament *Introduction* (the first edition 1750 preceded the full development of his powers and is a very different book from the later editions); his reprint of Lowth's *Prælectiones* with important additions (1758-62); his German translation of the Bible with notes (1773-92); his *Orientalische und Exegetische Bibliothek* (1771-89) and *Neue O. and E. Bib.* (1786-91); his *Mosaisches Recht* (1770-71); and his edition of Castle's *Lexicon Syriacum* (1787-88). His *Litterarischer Briefwechsel* (1794-96) contains much that is interesting for the history of learning in his time. (W. R. S.)

MICHAUD, JOSEPH (1767-1839),

French historian and publicist, was born of an old family on June 19, 1767, at Albens, Savoy, was educated at Bourg-en-Bresse, and afterwards engaged in literary work at Lyons, where the events of 1789 first called into activity the dislike to revolutionary principles which manifested itself throughout the rest of his life. In 1791 he went to Paris, where, not without danger, he took part in editing several royalist journals. In 1794 he started *La Quotidienne*, for his connexion with which he was arrested after the 13th of Vendemiaire; he succeeded in escaping his captors, but was sentenced to death *par contumace* by the military council. Having resumed the editorship of his newspaper on the establishment of the Directory, he was again proscribed on the 18th of Fructidor, but at the close of two years returned to Paris when the consulate had superseded the Directory. His Bourbon sympathies led to a brief imprisonment in 1800, and on his release he for the time abandoned journalism, and began to write or edit books. Along with his brother and two colleagues he published in 1806 a *Biographie moderne, ou dictionnaire des hommes qui se sont fait un nom en Europe depuis 1789*, the earliest work of its kind; in 1808 the first volume of his *Histoire des Croisades* appeared, and in 1811 he originated the *Biographie Universelle*. In 1814 he resumed the editorship of the *Quotidienne*, and in the same year was elected Academician. In 1815 his brochure entitled *Histoire des quinze Semaines ou le dernier regne de Bonaparte* met with extraordinary success, passing through twenty-seven editions within a very short time. His political services were now rewarded with the cross of an officer in the Legion of Honour and the modest post of king's reader, of which last he was deprived in 1827 for having opposed Peyronnet's "Loi d'Amour" against the freedom of the press. In 1830-31 he travelled in Syria and Egypt for the purpose of collecting additional materials for the *Histoire des Croisades*; his correspondence with a fellow explorer, Poujoulat, consisting practically of discussions and elucidations of various important points in that work, was afterwards published (*Correspondance d'Orient*, 7 vols., 1832-35). The *Bibliotheque des Croisades*, in four volumes more, contained the "pieces justificatives" of the *Histoire*. Michaud died on September 30, 1839, at Passy, where his home had been since 1832. His *Histoire des Croisades* was published in its final form in six volumes in 1841 under the editorship of his friend Poujoulat (9th ed., with appendix, by Huillard-Bréholles, 1856). Michaud along with Poujoulat also edited and in part wrote *Nouvelle Collection des Mémoires pour servir à l'Histoire de France*, 32 vols., 1836-44. See Sainte-Beuve, *Causeries du Lundi*, vol. vii.

MICHAUX, ANDRE (1746-1802),

a French botanist, best known for his works on the flora of North America and as a botanical traveller. In 1779 he spent some time botanizing in England, and in 1780 he explored Auvergne, the Pyrenees, and the north of Spain. In 1782 he was sent by the French Government on a botanical mission to Persia. His journey began unfavourably, as he was robbed by Arabs of all his equipments except his books; but he gained influential support in Persia, having cured the shah of a dangerous illness. After two years he returned to France with a fine herbarium, and also introduced numerous Eastern plants into the botanic gardens of France. In 1785 he was sent by the French Government to North America, and travelled through Canada, Nova Scotia, and the United States as far west as the Mississippi. The outbreak of the French Revolution deprived him of means to continue his work in America, and in 1796 he returned to France. He was shipwrecked, and lost most of his collections on the voyage. In 1800

---

formed with the officers that procured him the Paris MS. from which he edited Abulfeda's description of Egypt.

[1] *Curæ in Actus Apostolorum Syriacos*, 1755.

he went to Madagascar to investigate the flora of that island, and died there in 1802 His work as a botanist was chiefly done in the field, and he added largely to what was previously known of the botany of the East and of America He also introduced many plants into European botanic gardens He wrote two valuable works on North American plants,—the *Histoire des chênes de l'Amerique Septentrionale* (1801), with 36 plates, and the *Flora Boreali-Americana* (1803), 2 vols, with 51 plates

MICHAUX, FRANÇOIS ANDRE (1770–1855), son of the preceding, was, like his father, employed by the French Government to explore the forests of North America with a view to the introduction into France of trees valuable for their wood or other products He was very successful in carrying out this object He published in 1810-13 a *Histoire des Arbres forestieres de l'Amerique Septentrionale*, in 3 vols, with 156 plates, a work full of information on the characters, uses, distribution, and other points of interest in the various species In 1817–19 a translation of it appeared under the title *North American Sylva* He also wrote a *Voyage a l'ouest des Monts Alleghanys*, 1804, besides articles in scientific magazines

MICHELANGELO (1475–1564) Michelangelo Buonarroti, best known simply as Michelangelo, the last and most famous of the great artists of Florence, was the son of Ludovico Buonarroti, a poor gentleman of that city, and of his wife Francesca di Neri Ludovico was barely able to live on the income of his estate, but made it his boast that he had never stooped to add to it by mercantile or mechanical pursuits The favour of the Medici procured him employment in some minor offices of state, and in the autumn of 1474 he was appointed resident magistrate of Caprese, in the Casentino, for a period of six months Thither he accordingly repaired with his family, and there, on March 6, 1475, his second son Michelagniolo or Michelangelo was born Immediately afterwards the family returned to Florence, and the child was put to nurse with a marble worker's wife of Settignano His mother's health had already, it would seem, begun to fail, at all events in about two years from this time, after she had borne her husband two more sons, she died While still a young boy, Michelangelo determined in spite of his father's opposition to be an artist He had sucked in the passion, as he himself used to say, with his foster mother's milk After a sharp struggle, his stubborn will overcame his father's pride of gentility, and at thirteen he got himself articled as a paid assistant in the workshop of the brothers Ghirlandaio Domenico Ghirlandaio, bred a jeweller, had become by this time the foremost painter of Florence In his service the young Michelangelo laid the foundations of that skill in fresco with which twenty years afterwards he confounded his detractors at Rome He studied also, like all the Florentine artists of that age, in the Brancacci chapel, where the frescos of Masaccio, painted some sixty years before, still victoriously held their own and here, in a quarrel with an ill conditioned fellow student Torrigiani, he received the blow of which his face bore the marks to his dying day

Though Michelangelo's earliest studies were directed towards painting, he was by nature and predilection much more inclined to sculpture In that art he presently received encouragement and training under the eye of an illustrious patron, Lorenzo dei Medici On the recommendation, it is said, of Ghirlandaio, he was transferred, before the term of his apprenticeship as a painter had expired, to the school of sculpture established by Lorenzo in the Medici gardens Here he could learn to match himself against his great predecessor, Donatello, one of whose pupils was the director of the school, and to compare the works of that master and his Tuscan contemporaries with the antiques collected for the instruction of the scholars. Here, too, he could listen to discourses on Platonism, and steep himself in the doctrines of an enthusiastic philosophy which sought to reconcile with Christian faith the lore and the doctrines of the Academy Michelangelo remained a Christian Platonist to the end of his days, he was also from his youth up a devoted student of Dante His powers of mind and hand soon attracted attention, and secured him the regard and favour of his patrons in spite of his rugged, unsociable exterior, and of a temper which at best was but a half smothered volcano

Michelangelo had been attached to the school and household of the Medici for barely three years when, in 1492, his great patron Lorenzo died Lorenzo's son Piero dei Medici inherited the position, but not the qualities, of his father, Florence soon chafed under his authority, and towards the autumn of 1494 it became apparent that disaster was impending over him and his adherents Michelangelo was constitutionally subject to dark and sudden presentiments one such seized him now, and, without awaiting the popular outbreak which soon followed, he took horse with two companions and fled to Bologna There, being now in his twentieth year, he was received with kindness by a member of the Aldovrandi family, and on his commission executed two figures of saints, and one of an angel, for the shrine of St Dominic in the church of St Petronius After about a year, work at Bologna failing, and his name having been included in his absence on the list of artists appointed to provide a new hall of assembly for the Great Council of Florence, Michelangelo returned home The strange theocracy established by Savonarola was now in force, and the whole character of civic life at Florence was for the time being changed But Michelangelo was not left without employment He found a friend in another Lorenzo, the son of Pierfrancesco dei Medici, for whom he at this time executed a statue of the boy St John Having also carved a recumbent Cupid in imitation of the antique, it was suggested to him by the same patron that it should be so tinted and treated as to look like a real antique, and sold accordingly Without increasing the price he put upon the work Michelangelo for amusement lent himself to the counterfeit and the piece was then actually sold for a large sum to a Roman collector, the cardinal San Giorgio, as a genuine work of antiquity,—the dealer appropriating the profits When presently the cardinal discovered the fraud, he caused the dealer to refund, but as to Michelangelo himself, it was represented to the young sculptor that if he went to Rome the amateur who had just involuntarily paid so high a tribute to his skill would certainly befriend him He set forth accordingly, and arrived at Rome for the first time at the end of June 1496 Such hopes as he may have entertained of countenance from the cardinal San Giorgio were quickly dispelled Neither did the banished Piero dei Medici, who also was now living at Rome, do anything to help him On the other hand Michelangelo won the favour of a Roman nobleman, Jacopo Galli, and through him of the French cardinal Jean de Villiers de la Grolaie, abbot of St Denis From the former he received a commission for a Cupid and a Bacchus, from the latter for a *Pietà* or Mary lamenting over the body of Christ —works of which probably all three, the last two certainly, are preserved

Michelangelo's stay in Rome at this time lasted five years, from the summer of 1496 till that of 1501 The interval had been one of extreme political distraction at Florence The excitement of the French invasion, the mystic and ascetic regimen of Savonarola, the reaction which led to his overthrow, and finally the external wars and internal dissidences which preceded a new settlement, had all created an atmosphere most unfavourable to art

Nevertheless Ludovico Buonarroti, who in the troubles of 1494 had lost a small permanent appointment he held in the customs, and had come to regard his son Michelangelo as the mainstay of his house, had been repeatedly urging him to come home

A spirit of family duty and family pride was the ruling principle in all Michelangelo's conduct During the best years of his life he submitted himself sternly and without a murmur to pinching hardship and almost superhuman labour for the sake of his father and brothers, who were ever selfishly ready to be fed and helped by him Having now, after an illness, come home in 1501, Michelangelo received the request from the cardinal Francesco Piccolomini to adorn with a number of sculptured figures a shrine already begun in the cathedral of Siena in honour of the most distinguished member of his house, Pope Pius II Four only of these figures were ever executed, and those not apparently, or only in small part, by the master's hand A work of greater interest in Florence itself had diverted him from his engagement to his Sienese patron This was the execution of the famous colossal statue of David, popularly known as the Giant It was carved out of a huge block of marble on which another sculptor, Agostino d Antonio, had begun unsuccessfully to work forty years before, and which had been lying idle ever since Michelangelo had here a difficult problem before him Without much regard to tradition or the historical character of his hero, he carved out of the vast but cramped mass of material a youthful, frowning colossus, which amazed every beholder by its freedom and science of execution, and its victorious energy of expression All the best artists of Florence were called in council to determine on what site it should be set up, and after much debate the terrace of the Palace of the Signory was chosen, in preference to the neighbouring Loggia dei Lanzi Here accordingly the colossal David of Michelangelo took, in the month of May 1504, the place which it continued to hold ever afterwards, until ten years ago, in 1873, it was removed for the sake of protection to a hall in the Academy of Fine Arts Other works of sculpture by the same indomitable hand also belong to this period among these another David, in bronze, and on a smaller scale, a great rough hewn St Matthew begun but never completed for the cathedral of Florence a Madonna and Child executed on the commission of a merchant of Bruges, and two unfinished bas reliefs of the same subject

Neither was Michelangelo idle at the same time as a painter Leaving disputed works for the moment out of sight, he in these days at any rate painted for his and Raphael's common patron, Angelo Doni, the Holy Family now in the Uffizi at Florence And in the autumn of 1504, the year of the completion of the David, he received from the Florentine state a commission for a work of monumental painting on an heroic scale Leonardo da Vinci had been for some months engaged on his great cartoon of the Battle of Anghiari, to be painted on the wall of the great hall of the municipal council The gonfaloniere Soderini now procured for Michelangelo the commission to design a companion work Michelangelo chose an incident of the Pisan war, when the Florentine soldiery had been surprised by the enemy in the act of bathing he dashed at the task with his accustomed fiery energy, and had carried a great part of the cartoon to completion when, in the early spring of 1505, he broke off the work in order to obey a call to Rome which reached him from Pope Julius II His unfinished cartoon showed how greatly Michelangelo had profited by the example of his elder rival, Leonardo, little as, personally, he yielded to his charm or could bring himself to respond to his courtesy The work of Michelangelo's youth is for the most part comparatively tranquil in character His early sculpture, showing a degree of science and perfection unequalled since the antique, has also something of the antique serenity It bears strongly the stamp of intellectual research, but not by any means that of storm or strain In the cartoon of the Bathers, he on the other hand appropriated and carried further the mastery, which Leonardo had first asserted, over every variety of violent action and every extreme of energetic movement In it the qualities afterwards proverbially associated with Michelangelo—his *furia*, his *terribilita*, the tempest and hurricane of the spirit which accompanied his unequalled technical mastery and knowledge—first found expression.

With Michelangelo's departure to Rome early in 1505 the first part of his artistic career may be said to end It will be convenient here to recapitulate its principal results in sculpture and painting, both those preserved and those recorded but lost

SCULPTURE —Florence, 1489–94 *Head of a Faun*, National Museum, Florence (?) Condivi describes Michelangelo's first essay in sculpture as a head of an aged faun with a front tooth knocked out, this latter point having been an afterthought suggested by Lorenzo dei Medici The head is commonly identified with one in the National Museum at Florence, which, however, bears no marks of Michelangelo's style, and is in all probability spurious *Madonna Seated on a Step*, Casa Buonarroti Florence This bas relief is a genuine example of Michelangelo's early work in the Medicean school under Bertoldo It is executed in low relief in imitation of the technical style of Donatello, but the attitudes and characters of the figures and the long drawn, somewhat tormented folds of drapery, recall rather the manner of Jacopo della Quercia *Centauromachia*, Casa Buonarroti A fine and unquestionably genuine work in full relief, of probably somewhat later date than the last mentioned, Michelangelo has followed the antique in his conception and treatment of the nude, but not at all in the arrangement of the subject, which occurs frequently in works of ancient art.

Bologna 1494–95 *Kneeling Angel*, supporting the shrine of St Dominic This is the figure, with crisp hair, short resolute features, and drapery clinging to show the limbs, on the right-hand side of the spectator as he fronts the altar The prettier and more engaging figure at the opposite end was long taken to be Michelangelo's work, but is really that of Niccolo dell' Arca Michelangelo also finished the figure of St Petronius on the cornice of the same altar, begun by the same Niccolo, and executed one of St Proculus which has perished

Florence, 1495–96 *St John in the Wilderness*, Berlin Museum During the year between Michelangelo's return from Bologna and his first departure to Rome he executed, as has been narrated above, a statue of S Giovannino for Lorenzo di Pierfrancesco dei Medici This had for centuries been supposed lost, when in 1874 it was declared to have been found in the possession of Count Gualandi-Rossalmini at Pisa Vehement and prolonged discussions arose as to the authenticity of the work, and at last it was bought for the Berlin Museum, where its genuineness is with apparently good reason maintained The stripling saint stands naked but for a skin about his loins, holding a honeycomb in his left hand and lifting to his mouth a goat's horn full of honey with his right *Restoration of an antique group of Bacchus and Ampelus*, Uffizi Gallery Florence This interesting restoration of an antique torso, by the addition of a head the lower part of the legs, and the accessory figure of an attendant genius, a plinth, and mask, is not one of the works traditionally ascribed to Michelangelo but has lately, and as it seems rightly been claimed for him on internal evidence *Recumbent Cupid* bought by the cardinal San Giorgio as an antique This work which played an important part in Michelangelo's history, is unfortunately lost

Rome, 1495 1501 *Kneeling Cupid*, South Kensington Museum, London This beautiful statue of an athletic youth kneeling on the right knee, looking over his right shoulder, with the right hand lowered and the left raised and having a quiver on the ground beside him is acknowledged on internal grounds as an early work of Michelangelo There is some ambiguity about the character and action of the personage but the work is usually identified with the Cupid which Michelangelo is recorded to have executed at this time for Jacopo Galli *Bacchus and Young Faun*, National Museum Florence This is unquestionably the Bacchus commissioned by the same patron The finely framed but soft limbed youthful god, his weight supported somewhat staggeringly on the left leg holds up a wine cup in his right hand and with his loosely hanging left hand holds a cluster of grapes at which a child faun standing a little behind him grasps and nibbles The surface highly finished and polished as in the Berlin St John *Virgin Lamenting the Dead Christ* St Peter's, Rome This group, executed for the French abbot of St Denis, is the finest of all

Michelangelo's early sculptures, and one of the finest of his life It still recalls the ideals of some of the earlier Tuscan masters, especially Jacopo da Quercia, but the execution is of a mastery and nobility unprecedented in Italian art The Virgin, in drapery of magnificent design, with her left knee somewhat raised and her right hand slightly extended, sits holding on her lap the dead Christ,—a figure of splendid frame and modelling as well as of admirable pathos and dignity in expression

Florence 1501–6 *Four Saints decorating the Shrine of Pius II*, in the cathedral of Siena These figures represent the only part which Michelangelo ever completed of his contract with the cardinal Piccolomini and his heirs They are evidently carried out by the hand of pupils only *Virgin and Child*, Liebfrauenkirche Bruges This pleasing group has been since the days of Albert Durer attributed to Michelangelo and bears the manifest stamp of his design though its execution may be partly by inferior hands It is placed close to the tombstone of a member of the Moscheroni (or Moskeron) family We know that Michelangelo executed at this time for one of this very family, a work which the ancient biographers describe as having been in bronze —a medallion in that metal says explicitly Vasari but it is probably really the marble group in question *Virgin and Child* Royal Academy London This beautiful unfinished circular relief is identified with one recorded to have been executed by the master for Taddeo Gaddi *Virgin and Child* National Museum, Florence,—a similar relief also unfinished originally ordered by Bartolommeo Pitti *Youthful David*, Academy of Arts Florence Of this colossal work which in spite of its scale and subject has still in grace of pose and style a considerable artistic affinity with the earlier Bacchus and St John enough has been said *Figure of David*, a small statue in bronze Several extant works have been pointed out as probably identical with this lost statue, but the claims of none have been generally acknowledged

PAINTING —*Holy Family* Uffizi Florence This circular picture, painted for Angelo Doni and mentioned by the earliest biographers is the only perfectly well attested panel painting of Michelangelo which exists His love of restless and somewhat strained actions is illustrated by the action of the Madonna who kneels on the ground holding up the child on her right shoulder his love of the nude by the introduction (wherein he follows Luca Signorelli) of some otherwise purposeless undraped figures in the background *Virgin and Child with Four Angels* National Gallery London This unfinished painting marked by great grace as well as severity of feeling and design was formerly attributed to Domenico Ghirlandaio, but is now commonly held to be the earliest extant picture by Michelangelo Of his manner, especially in the design and treatment of the drapery, it bears evident marks but the execution seems like that of some weaker pupil or companion perhaps Ridolfo Ghirlandaio or Granacci *Entombment of Christ* National Gallery London This picture, also unfinished has in like manner been much contested Its composition is unfortunate weaker hands have disfigured some portions of the work but the extraordinary excellence of other portions and the grandeur of some of the actions, render it probable that the work is one begun and afterwards abandoned by Michelangelo himself *Cartoon of the Battle of Anghiari* Of this famous lost work (begun though apparently not completed in the period now engaging us) the only authentic record is contained in two early engravings one by Marcantonio and the other by Agostino Ve An elaborate drawing of many figures at Holkham Hall well known and often engraved, seems to be a later *cento* destitute of real authority

Michelangelo had not been long in Rome before Pope Julius devised fit employment for him That capacious and headstrong spirit, on fire with great enterprises, had conceived the idea of a sepulchral monument to commemorate his glory when he should be dead, and to be executed according to his own plans while he was still living He entrusted this congenial task to Michelangelo The design being approved, the artist spent the winter of 1505–6 at the quarries of Carrara, superintending the excavation and shipment of the necessary marbles In the spring he returned to Rome, and when the marbles arrived fell to with all his energy at the preparations for the work For a while the pope followed their progress eagerly and was all kindness to the young sculptor But presently his disposition changed In Michelangelo's absence an artist who was no friend of his, Bramante of Urbino, had been selected by Julius to carry out a new architectural scheme, commensurate with the usual vastness of his conceptions, namely the rebuilding of St Peter's church To the influence and the malice of Bramante Michelangelo attributed the unwelcome invitation he now received to interrupt the great work of sculpture which he had just begun, in order to decorate the Sixtine chapel with frescos Soon, however, schemes of war and conquest interposed to divert the thoughts of Julius, not from the progress of his own monument merely, but from artistic enterprises altogether One day Michelangelo heard him say at table to his jeweller that he meant to spend no more money on pebbles either small or great To add to the artist's discomfiture, when he went to apply in person for payments due, he was first put off from day to day, and at last actually with scant courtesy dismissed At this his dark mood got the mastery of him Convinced that not his employment only but his life was threatened, he suddenly took horse and left Rome, and before the messengers of the pope could overtake him was safe on Florentine territory Michelangelo's flight took place in April 1506 Once among his own people, he turned a deaf ear to all overtures made from Rome for his return, and stayed throughout the summer at Florence, how occupied we are not distinctly informed, but apparently, among other things, on the continuation of his great battle cartoon

During the same summer Julius planned and executed the victorious military campaign which ended in his unopposed entry at the head of his army into Bologna Thither, under strict safe conduct and promises of renewed favour, Michelangelo was at last prevailed on to betake himself Julius received the truant artist kindly, as indeed between these two volcanic natures there existed a natural affinity, and ordered of him his own colossal likeness in bronze, to be set up, as a symbol of his conquering authority, over the principal entrance of the church of St Petronius For the next fifteen months Michelangelo devoted his whole strength to this new task The price at which he undertook it left him, as it turned out, hardly any margin to subsist on Moreover, in the technical art of metal casting he was inexperienced, and an assistant whom he had summoned from Florence proved insubordinate and had to be dismissed Nevertheless his genius prevailed over every hardship and difficulty, and on the 21st of February 1508 the majestic bronze colossus of the seated pope, robed and mitred, with one hand grasping the keys and the other extended in a gesture of benediction and command, was duly raised to its station over the church porch Three years later it was destroyed in revolution The people of Bologna rose against the authority of Julius, his delegates and partisans were cast out, and his effigy hurled from its place The work of Michelangelo, after being trailed in derision through the streets, was broken up and its fragments cast into the furnace

Meanwhile the artist himself, as soon as his work was done, had followed his reconciled master back to Rome The task that here awaited him, however was after all not the resumption of the papal monument, but the execution of the series of paintings in the Sixtine chapel which had been mooted before his departure Painting, he always averred, was not his business and he entered with misgiving and reluctance upon his new undertaking Destiny, however so ruled that the work thus thrust upon him remains his chief title to glory His history is one of indomitable will and almost superhuman energy, yet of will that hardly ever had its way and of energy continually at war with circumstance The only work which in all his life he was able to complete as he had conceived it was this of the decoration of the Sixtine ceiling The pope had at first proposed a scheme including figures of the twelve apostles only Michelangelo would be content with nought so meagre, and furnished instead a design of many hundred figures, embodying all the history of creation and of the first patriarchs, with accessory personages of prophets and sibyls dreaming on the new dispensation to come, and, in addition, those of the forefathers of Christ. The whole was to be enclosed and divided by an elaborate framework of painted architecture with a multitude of nameless human shapes supporting its several members or reposing among them,—shapes mediating, as it were, between the features of the inanimate framework and those of the great dramatic and prophetic scenes themselves. Michelangelo's plan was accepted by the pope, and by May 1508 his preparations for its execution were made. Later in the same year he summoned a number of assistant painters from Florence. Trained in the traditions of the earlier Florentine school, they were unable, it seems, to interpret Michelangelo's designs in fresco either with sufficient freedom or sufficient uniformity of style to satisfy him. At any rate he soon dismissed them, and carried out the remainder of his colossal task alone, except for the necessary amount of purely mechanical and subordinate help. The physical conditions of prolonged work, face upwards, upon this vast expanse of ceiling were adverse and trying in the extreme. But after four and a half years of toil the task was accomplished. Michelangelo had during its progress been harassed alike by delays of payment and by hostile intrigue. The absolute need of funds for the furtherance of the undertaking had even constrained him at one moment to break off work and pursue his inconsiderate master as far as Bologna. His ill wishers at the same time kept casting doubts on his capacity, and vaunting the superior powers of Raphael. That gentle spirit would by nature have been no man's enemy, but unluckily Michelangelo's moody, self concentrated temper prevented the two artists being on terms of amity such as might have stopped the mouths of mischief makers. Once during the progress of his task Michelangelo was compelled to remove a portion of the scaffolding and exhibit what had been so far done, when the effect alike upon friends and detractors was overwhelming. Still more complete was his triumph when, late in the autumn of 1512, the whole of his vast achievement was disclosed to view.

The main field of the Sixtine ceiling is divided into four larger alternating with five smaller fields. The following is the order of the subjects depicted in them:—(1) the dividing of the light from the darkness; (2) the creation of sun, moon and stars, and of the herbage; (3) the creation of the waters; (4) the creation of man; (5) the creation of woman; (6) the temptation and expulsion; (7) an enigmatical scene said to represent the sacrifice of Cain and Abel, but rather resembling the sacrifice of Noah; (8) the deluge; (9) the drunkenness of Noah. The figures in the last three of these scenes are on a smaller scale than those in the first six. In numbers 1, 3, 5, 7, and 9 the field of the picture is reduced by the encroachments of the architectural framework and supporters. These subjects are flanked at each end by the figure of a seated prophet or sibyl alternately; two other prophets are introduced at each extremity of the series, making seven prophets and five sibyls in all. In the angles to right and left of the prophets at the two extremities are the Death of Goliath, the Death of Judith, the Brazen Serpent, and the Punishment of Haman. In the twelve lunettes above the windows and the similar number of triangular vaulted spaces over them are mysterious groups or pairs of groups of figures which from Michelangelo's own time have usually been known as Ancestors of Christ. The army of nameless architectural and subordinate figures is too numerous to be here spoken of. The work represents all the powers of Michelangelo at their best. Disdaining all the accessory allurements of the painter's art, he has concentrated himself upon the exclusive delineation of the human form and face at their highest power. His imagination has conceived and his knowledge and certainty of hand have enabled him to realize, attitudes and combinations of unmatched variety and grandeur, and countenances of unmatched expressiveness and power. But he has not trusted, as he came later to trust, to science and acquired knowledge merely; neither do his personages, so far as they did afterwards, transcend human possibility or leave the facts of actual life behind them. In a word, his sublimity, often in excess of the occasion, is here no more than equal to it; moreover it is combined with the noblest elements of grace and even of tenderness. As for the intellectual meanings of his vast design, over and above those which reveal themselves at a first glance or by a bare description,—they are from the nature of the case inexhaustible, and can never be perfectly defined. Whatever the soul of this great Florentine, the spiritual heir of Dante, with the Christianity of the Middle Age not shaken in his mind, but expanded and transcendentalized, by the knowledge and love of Plato,—whatever the soul of such a man, full of suppressed tenderness and righteous indignation, and of anxious questionings of coming fate, could conceive, that Michelangelo has expressed or shadowed forth in this great and significant scheme of paintings. The details it must remain for every fresh student to interpret in his own manner.

The Sixtine chapel was no sooner completed than Michelangelo resumed work upon the marbles for the monument of Julius. But four months only had passed when Julius died. His heirs immediately entered (in the summer of 1513) into a new contract with Michelangelo for the execution of the monument on a reduced scale. What the precise nature and extent of the original design had been we do not know, but the new one was extensive and magnificent enough. It was to consist of a great quadrilateral structure, two courses high, projecting from the church wall, and decorated on its three unattached sides with statues. On the upper course was to be placed the colossal recumbent figure of the pope under a canopy, and beside it mourning angels, with prophetic and allegoric personages at the angles,—sixteen figures in all. The lower course was to be enriched with twenty four figures in niches and on projecting pedestals,—in the niches, Victories trampling on conquered Provinces; in the pedestals, Arts and Sciences in bondage. The entire work was to be completed in nine years' time. During the next three years, it would seem, Michelangelo brought to completion three at least of the promised figures, and they are among the most famous of all existing works of the sculptor's art,—namely, the Moses now in the church of S. Pietro in Vincoli at Rome and the two "Slaves" at the Louvre.

The Moses, originally intended for one of the angles of the upper course, is now placed at the level of the eye, in the centre of the principal face of the monument as it was at last finished, on a deplorably reduced and altered scale, by Michelangelo and his assistants in his old age. The prophet, heavily bearded and draped, with only his right arm bare, sits with his left foot drawn back, his head raised and turned to the left with an expression of indignation and menace, his left hand laid on his lap and his right grasping the tables of the law. The work, except in one or two places, is of the utmost finish, and the statue looks like one of the prophets of the Sixtine ceiling done in marble. The Slaves at the Louvre are youthful male figures of equally perfect execution, nude but for the band which passes over the breast of one and the right leg of the other. One, with his left hand raised to his head and his right pressed to his bosom and his eyes almost closed, seems succumbing to the agonies of death; the other, with his arms bound behind his back, looks upward still hopelessly struggling. There is reason to believe that all three of these figures were finished between 1513 and 1516. The beginnings of other figures or groups intended for the same monument are to be found at Florence, where they were no doubt made and then abandoned some years later,—viz. four rudely blocked figures of slaves or prisoners in a grotto of the Boboli gardens, and the so-called Victory in the National Museum, an unfinished group of a combatant kneeling on and crushing to death a fallen enemy; with these may be associated a wax model known as Hercules and Cacus in the South Kensington Museum, and the figure of a crouching man at St Petersburg.

By this time (1516) Michelangelo's evil star was again in the ascendant. Julius II. had been succeeded on the papal throne by a Medici under the title of Leo X. The Medici, too, had about the same time by force and fraud re-established their sway in Florence, overthrowing the free institutions that had prevailed there since the days of Savonarola. Now on the one hand this family were the hereditary friends and patrons of Michelangelo, on the other hand he was a patriotic son of republican Florence, so that henceforward his personal allegiance and his political sympathies were destined to be at conflict. Over much of his art, as has been thought, the pain and perplexity of this conflict have cast their shadow For the present the consequence to him of the rise to power of the Medici was a fresh interruption of his cherished work on the tomb of Julius Leo X and his kinsmen insisted that Michelangelo, regardless of all other engagements, must design and carry out a great new scheme for the enrichment of their own family church of San Lorenzo in Florence The heirs of Julius on their part showed an accommodating temper, and at the request of Leo allowed their three years' old contract to be cancelled in favour of another, whereby the scale and sculptured decorations of the Julian monument were again to be reduced by nearly a half Unwillingly Michelangelo accepted the new commission thus thrust upon him for the church façade at Florence, but, having once accepted it, he produced a design of combined sculpture and architecture as splendid and ambitious in its way as had been that for the monument of Julius In the summer of 1516 he left Rome for Carrara to superintend the excavation of the marbles

Michelangelo was now in his forty second year Though more than half his life was yet to come, yet its best days had, as it proved, been spent All the hindrances which he had encountered hitherto were as nothing to those which began to beset him now For the supply of materials for the façade of San Lorenzo he had set a firm of masons to work, and had himself, it seems, entered into a kind of partnership with them, at Carrara, where he knew the quarries well, and where the industry was hereditary and well understood When all was well in progress there under his own eye, reasons of state induced the Medici and the Florentine magistracy to bid him resort instead to certain new quarries at Pietrasanta, near Seravalle in the territory of Florence Hither, to the disgust of his old clients at Carrara and to his own, Michelangelo accordingly had to transfer the scene of his labours Presently he found himself so impeded and enraged by the mechanical difficulties of raising and transporting the marbles, and by the disloyalty and incompetence of those with whom he had to deal, that he was fain to throw up the commission altogether The contracts for the façade of San Lorenzo were rescinded in March 1518, and the whole magnificent scheme came to nothing Michelangelo then returned to Florence, where proposals of work poured in on him from many quarters The king of France desired something from his hand to place beside the two pictures he possessed by Raphael The authorities of Bologna wanted him to design a façade for their church of St Petronius, those of Genoa to cast a statue in bronze of their great commander, Andrea Doria Cardinal Grimani begged hard for any picture or statue he might have to spare other amateurs importuned him for so much as a pencil drawing or sketch Lastly his friend and partisan Sebastian del Piombo at Rome, ever eager to keep up the feud between the followers of Michelangelo and those of Raphael, besought him on Raphael's death to return at once to Rome, and take out of the hands of the dead master's pupils the works of painting still remaining to be done in the Vatican chambers Michelangelo complied with none of these requests All that we know of his doing at this time was the finishing a commission received and first put in hand four years previously, for a full sized statue of a nude Christ grasping the Cross This statue, completed and sent to Rome in 1521 (with some last touches added by subordinate hands in Rome itself), stands now in the church of Sta Maria sopra Minerva, there is little in it of the Christian spirit as commonly understood, although, in those parts which Michelangelo himself finished, there is extreme accomplishment of design and workmanship

The next twelve years of Michelangelo's life (1522–34) were spent at Florence. and again employed principally in the service of his capricious and uncongenial patrons, the Medici The plan of a great group of monuments to deceased members of this family, to be set up in their mortuary chapel in San Lorenzo, seems to have been formed, and preparations to have been made by Michelangelo for its execution, as early as 1519 It was not, however, until 1524, after Leo X had died, and his successor Adrian VI had been in his turn succeeded by another Medicean pope, Clement VII, that any practical impulse was given to the work Even then the impulse was a wavering one. First Clement proposed to associate another artist, Sansavino with Michelangelo in his task This proposal being on Michelangelo's peremptory demand abandoned, Clement next distracted the artist with an order for a new architectural design,—that, namely, for the proposed Medicean or "Laurentian" library When at last the plans for the sepulchral monuments took shape, they did not include, as had been at first intended, memorials to the founders of the house's greatness, Cosimo and Lorenzo the Magnificent, or even to Pope Leo X himself, but only to two younger members of the house lately deceased, Giuliano, duke of Nemours, and Lorenzo, duke of Urbino Michelangelo brooded long over his designs for this work, and was still engaged on its execution—his time being partly also taken up by the building plans for the Medicean library—when political revolutions interposed to divert his industry In 1527 came to pass the sack of Rome by the Austrians, and the apparently irretrievable ruin of Pope Clement The Florentines seized the occasion to expel the Medici from their city, and set up a free republican government once more Naturally no more funds for the work in San Lorenzo were forthcoming, and Michelangelo, on the invitation of the new signory, occupied himself for a while with designs for a colossal group of Samson and the Philistines, to be wrought out of a block of marble which had been rough hewn already for another purpose by Baccio Bandinelli Soon, however, he was called to help in defending the city itself from danger Clement and his enemy Charles V having become reconciled, both alike were now bent on bringing Florence again under the rule of the Medici In view of the approaching siege, Michelangelo was appointed engineer in chief of the fortifications He spent the early summer of 1529 in strengthening the defences of San Miniato, from July to September he was absent on a diplomatic mission to Ferrara and Venice Returning in the middle of the latter month, he found the cause of Florence hopeless from internal treachery and from the overwhelming strength of her enemies One of his dark seizures overcame him, and he departed again suddenly for Venice Not cowardice, but despair of his city's liberties, and still more of his own professional prospects amid the turmoil of Italian affairs, was the motive of his departure For a while he remained in Venice, negotiating for a future residence in France Then, while the siege was still in progress, he returned once more to Florence, but in the final death struggle of her liberties he bore no part When in 1530 the city submitted to her conquerors, no mercy was shown to most of those who had taken part in her defence Michelangelo believed himself in danger with the rest, but on the intervention of Baccio Valori he was presently taken back into favour and employment by Pope Clement For three years more he still remained at Florence, engaged principally on the completion of the Medici monuments, and on the continuance of the Medicean library, but partly also on a picture of Leda for the duke of Ferrara

The statues of the Medici monument take rank beside the Moses and the Slaves as the finest work of Michelangelo's central time in sculpture, moreover, though some of the figures are unfinished, they constitute as actually executed a complete scheme They consist of a Madonna and Child (left imperfect because the marble was short in bulk), and of the two famous monumental groups, each consisting of an armed and seated portrait statue in a niche, with two emblematic figures reclining on each side of a sarcophagus below The portraits are treated not realistically but typically In that of Lorenzo seems to be typified the mood of brooding and concentrated inward thought preparatory to warlike action, in that of Giuliano the type of alert and confident practical survey immediately preceding the moment of action To this contrast of the meditative and active characters corresponds to some extent a contrast in the emblematic groups accompanying the portraits At the feet of the Duke Giuliano recline the shapes of Night and Day,—the former a female, the latter a male personification —the former sunk in an attitude of deep but uneasy slumber the latter (whose head and face are merely blocked out of the marble) lifting himself in one of wrathful and disturbed awakening But for Michelangelo s unfailing grandeur of style, and for the sense which his works convey of a compulsive heat and tempest of thought and feeling in the soul that thus conceived them both these attitudes might be charged with extravagance As grand but far less violent are those of the two companion figures that recline between sleep and waking on the sarcophagus of the pensive Lorenzo Of these, the male figure is known as Evening and the female as Morning (*Crepuscolo* and *Aurora*) In Michelangelo s original idea figures of Earth and Heaven were to be associated with those of Night and Day on the monument of Giuliano and others of a corresponding nature, no doubt with those of the Morning and Evening Twilight on that of Lorenzo these figures afterwards fell out of the scheme Michelangelo s obvious and fundamental idea was as some words of his own record to exhibit the elements and the powers of earth and heaven lamenting the death of the princes, it is a question of much interest but not to be discussed here, what other ideas of a more personal and deeper kind may have conflicted or come into association with these, and found expression in these majestic works of art whereof no one who looks upon them can escape the spell

Michelangelo had never ceased to be troubled by the heirs and executors of Julius, as well as by his own artistic conscience and ambition, concerning the long postponed completion of the Julian monument Agreement after agreement had been made, and then from the force of circumstances broken In 1532, on the completion of the Medicean monuments at Florence, he entered into a new and what he firmly meant to be a binding contract to complete the work, on a scale once more very greatly reduced, and to set it up in the church of S Pietro in Vincoli in Rome But once more the demands of the pope diverted his purpose Clement insisted that Michelangelo must complete his decorations of the Sixtine chapel by painting anew the great end wall above the altar, adorned until then by frescos of Perugino The subject chosen was the Last Judgment, and Michelangelo began to prepare sketches For the next two years he lived between Rome and Florence, and in the autumn of 1534, in his sixtieth year, settled finally and for the remainder of his life at Rome Immediately afterwards Pope Clement died, and was succeeded by Farnese under the title of Paul III Even more than his predecessor, Paul insisted on claiming the main services of Michelangelo for himself, and forced him to let all other engagements drift For the first seven years after the artist s return to Rome, his time was principally taken up with the painting of the colossal and multitudinous Last Judgment This being completed in 1541, he was next compelled to undertake two more great frescos, one of the Conversion of Paul and another of the Martyrdom of Peter, in a new chapel which the pope had caused to be built in the Vatican, and named after himself *Capella Paolina*

The fresco of the Last Judgment in the Sixtine chapel is probably the most famous single picture in the world In it Michelangelo shows more than ever the omnipotence of his artistic science, and the fiery daring of his conceptions The work exhibits the athletic unclothed human form in every variety and extremity of hitherto unattempted action and predicament But of moderation, as well as of beauty and tenderness it is almost entirely devoid Whether from the complexion of his own thoughts and the *sæva indignatio* that was native to his breast or from the influence of the passionate and embittered theological temper of the time, Michelangelo has here neglected the consolatory aspects of Christianity, and insisted on its terrific aspects almost exclusively Neither in the qualities of colour and execution is the work, so far as the condition of either admits comparison, comparable for charm to the earlier and far more nobly inspired frescos of the ceiling It is to these, and not to the Last Judgment, that the student must turn if he would realize what is best and greatest in the art of Michelangelo

The frescos of the Pauline Chapel are on their part in part so injured as to be hardly susceptible of useful study or criticism In their ruined state they bear evidence of the same tendencies that made the art of Michelangelo in its latest phase so dangerous an example to weaker men,—the tendency that is, to seek for energy and violence of action both in place and out, for "terribleness *quand même*, and to design actions not by help of direct study from nature, but by scientific deduction from the abstract laws of structure and movement At best these frescos can never have been happy examples of Michelangelo s art

During the fifteen years (1534–49) when Michelangelo was mainly engaged on these paintings, he had also at last been enabled to acquit himself, although in a manner that can have been satisfactory to none concerned, of his engagements to the heirs of Julius Once more the influence of the pope had prevailed on them to accept a compromise altogether to their disadvantage It was agreed that the Moses executed thirty years before should be the central figure of the new scheme, assistants were employed to carve two smaller flanking figures of female personifications, and the three were in 1545 set up in S Pietro in Vincoli in combination with an architectural structure of rich but incongruous design During the same years the long pent human elements of fervour and tenderness in Michelangelo s nature had found vent and utterance such as they had never found before He had occasionally practised poetry in youth, and there are signs of some transient love passage during his life at Bologna But it was not until towards his sixtieth year that the springs of feeling were fairly opened in the heart of this solitary, this masterful and stern, life wearied and labour hardened man Towards that age we find him beginning to address impassioned sonnets, of which the sentiment is curiously comparable to that expressed in some of Shakespeare s, to a beautiful and gifted youth, Tommaso Cavalieri Soon afterwards he made the acquaintance of the pious, accomplished, and high souled lady, Vittoria Colonna, widow of the Marquis Pescara For twelve years until her death, which happened in 1547, her friendship was the great solace of Michelangelo s life On her, in all loyalty and reverence, he poured out all the treasures of his mind, and all his imprisoned powers of tenderness and devotion He painted for her a crucifixion of extraordinary beauty, of which many imitations but not the original have come down to us She was the chief inspirer of his poetry,—in which, along with her praises, the main themes are the Christian religion, the joys of Platonic love, and the power and mysteries of art Michelangelo's poetical style is strenuous and concentrated like the man He wrote with labour and much self correction, we seem to feel him flinging himself on the material of language with the same overwhelming energy and vehemence,—the same impetuosity of temperament, combined with the same fierce desire of perfection,—with which contemporaries describe him as flinging himself on the material of marble

And so the mighty sculptor, painter, and poet reached old age An infirmity which settled on him in 1544, and the death of Vittoria Colonna in 1547, left him broken in health and heart But his strength held on for many a year longer yet His father and brothers were dead, and his family sentiment concentrated itself on a nephew, Leonardo, to whom he showed unremitting practical kindness, coupled with his usual suspiciousness and fitfulness of temper In almost all his relations the old man continued to the end to manifest the same loyal and righteous heart, accompanied by the same masterful, moody, and estranging temper, as in youth Among the artists of the younger generation he held a position of absolute ascendency and authority, nor was his example, as we have said, by any means altogether salutary for them. During the last years of his life he made but few more essays in sculpture, and those not successful, but was much employed in the fourth art in which he excelled, that of architecture. A succession of popes demanded his services for the embellishment of Rome. For Paul III. he built the palace called after the name of the pope's family the Farnese. On the death of Antonio da San Gallo he succeeded to the onerous and coveted office of chief architect of St Peter's Church, for which he remodelled all the designs, living to see some of the main features, including the supports and lower portion of the great central dome, carried out in spite of all obstacles according to his plans. Other great architectural tasks on which he was engaged were the conversion of a portion of the Baths of Diocletian into the church of Sta Maria degli Angeli, and the embellishment and rearrangement of the great group of buildings on the Roman Capitol. At length, in the midst of these vast schemes and responsibilities, the heroic old man's last remains of strength gave way. He died on the threshold of his ninetieth year, on the 18th of February 1564.

For the bibliography of Michelangelo, which is extensive, see the useful though very imperfect compilation of Passerini, *Bibliografia di Michelangelo Buonarroti*, &c., Florence, 1875. The most important works, taken in chronological order, are the following:—P. Giovio, supplement to the fragmentary *Dialogus de viris litteris illustribus*, written soon after 1527, first published by Tiraboschi, *Storia della Letteratura italiana*, Modena 1871; G. Vasari, in *Vite degli più eccellenti architettori, pittori, e scultori*, &c., Florence, 1550; A. Condivi, *Vita di Michelangelo Buonarroti*, 1553, this account, for which the author, a pupil and friend of the master's, had long been collecting materials, was much fuller than that of Vasari, who made use of it in rewriting his own life of Michelangelo for his second edition, which appeared after the master's death (1568). The best edition of Vasari is that by Milanesi, Florence, 1878-83; of Condivi, that by Gori and Mariette, Pisa, 1746. The first additions of importance were published by Bottari, *Raccolta di lettere sulla pittura*, &c., Rome, 1754 (2d ed., by Ticozzi, Milan, 1822); the next by Gaye, *Carteggio inedito* 1840. Portions of the correspondence preserved in the Buonarroti archives were published by Guasti in his notes to the *Rime di Michelangelo Buonarroti* 1863, and by Daelli in *Carte Michelangelesche inedite*, Milan, 1865. Complete biographies of Michelangelo had been meanwhile attempted by J. Harford, London, 1857, and with more power by Hermann Grimm *Leben Michelangelo's* Hanover (5th ed., 1879). A great increment of biographical material was at length obtained by the publication, in the four hundredth year after Michelangelo's birth, of the whole body of his letters preserved in the Buonarroti archives,—*Lettere di Michelangelo Buonarroti*, ed. G. Milanesi, Florence, 1875. This material was first employed in a connected narrative by A. Gotti, *Vita di Michelangelo*, Florence, 1875. Next followed C. Heath Wilson, *Life and Works of Michelangelo Buonarroti*, Florence, 1876, the technical remarks in which, especially as concerns the fresco paintings, are valuable. Lastly, the combined lives of Michelangelo and Raphael by Professor A. Springer in Dohme's series of *Kunst u. Künstler*, Leipsic, 1878, contain the best biography of the master which has yet appeared. Of the poems of Michelangelo the best edition is that already referred to,—G. Guasti, *Rime di Michelangelo Buonarroti*, 1863; in earlier additions the text had been recklessly tampered with, and the rugged individuality of the master's style smoothed down. An edition with German translations was published by Hasenclever, Leipsic, 1875; for the English student the translations by Mr J. A. Symonds, in *Sonnets of Michelangelo and Campanella*, London, 1878, are invaluable. (S. C.)

MICHELET, JULES (1798-1874), one of the most voluminous and remarkable writers of France, and one who only lacked a keener power of self-criticism to make him one of the greatest, was born at Paris, August 21, 1798. He belonged to a family which had Huguenot traditions, and which was latterly occupied in the art of printing. His father was a master printer, but seems not to have been very prosperous, and the son at an early age assisted him in the actual work of the press. A place was offered him in the imperial printing office, but his father was able to send him to the famous Collége or Lycée Charlemagne, where he distinguished himself. He passed the university examination in 1821, and was shortly after appointed to a professorship or rather mastership of history in the Collége Rollin. Soon after this, in 1824, he married. The period of the Restoration and the July monarchy was one of the most favourable to rising men of letters of a somewhat scholastic cast that has ever been known in France, and Michelet had powerful patrons in Villemain, Cousin, and others. But, though he was an ardent politician (having from his childhood embraced republicanism and a peculiar variety of romantic free thought), he was first of all a man of letters and an inquirer into the history of the past. His earliest works were school books, and they were not written at a very early age. Between 1825 and 1827 he produced divers sketches, chronological tables, &c., of modern history. His *Précis* of the subject, published in the last-mentioned year, is a sound and careful book, far better than anything that had appeared before it, and written in a sober yet interesting style. In the same year he was appointed maître de conférences at the École Normale. Four years later, in 1831, the *Introduction à l'Histoire Universelle* showed a very different style, exhibiting no doubt the idiosyncrasy and literary power of the writer to greater advantage, but also displaying the peculiar visionary qualities which make Michelet the most stimulating but the most untrustworthy (not in facts, which he never consciously falsifies, but in suggestion) of all historians. The events of 1830 had unmuzzled him, and had at the same time improved his prospects, and put him in a better position for study by obtaining for him a place in the Record Office, and a deputy professorship under Guizot in the literary faculty of the university. Very soon afterwards he began his chief and monumental work, the *Histoire de France*, which occupied him for about forty years, and of which we shall speak presently. But he accompanied this with numerous other works, chiefly of erudition, such as the *Œuvres Choisies de Vico*, the *Mémoires de Luther écrits par lui-même*, the *Origines du Droit Français*, and somewhat later the *Procès des Templiers*. 1838 was a year of great importance in Michelet's life. He was in the fulness of his powers, his studies had fed his natural aversion to the principles of authority and ecclesiasticism, and at a moment when the revived activity of the Jesuits caused some real and more pretended alarm he was appointed to the chair of history at the College de France. Assisted by his friend Quinet, he began a violent polemic against the unpopular order and the principles which it represented, a polemic which made their lectures, and especially Michelet's, one of the most popular resorts of the day. He published, in 1839, a History of the Roman Republic, but this was in his graver and earlier manner. The results of his lectures appeared in the volumes *Le Prêtre, la Femme, et la Famille* and *Le Peuple*. These books do not display the apocalyptic style which, borrowed to a certain though no very great extent from Lamennais, characterizes Michelet's later works, but they contain in miniature almost the whole of his curious ethico-politico-theological creed—a mixture of sentimentalism, communism, and anti-sacerdotalism, supported by the most eccentric arguments, but urged with a great deal of eloquence. The principles of the outbreak of 1848 were in the air, and Michelet was not the least important of those who condensed and propagated them; indeed his original lectures were of so incendiary a kind that the course had to be interdicted. But when the actual revolution broke out Michelet, unlike many other men of letters, did not attempt to enter on active political life, and merely devoted himself more strenuously to his literary work. Besides continuing the great history, he undertook and carried out, during the years between the downfall of Louis Philippe and the final establishment of Napoleon III., an enthusiastic *Histoire de la Révolution Française*. Despite or because of its enthusiasm, this is by no means Michelet's best book. The events were too near and too well known, and hardly admitted the picturesque sallies into the blue distance which make the charm and the danger of his larger work. In actual picturesqueness as well as in general veracity of picture, the book cannot approach Carlyle's, while as a mere chronicle of the events it is inferior to half a dozen prosaic histories older and younger than itself. The *coup d'état* lost Michelet his place in the Record Office, as, though not in any way identified with the republic administratively, he refused to take the oaths to the empire. But the new *régime* only kindled afresh his republican zeal, and his second marriage (with Mademoiselle Adèle Mialaret, a lady of some literary capacity, and of republican belongings) seems to have further stimulated his powers. While the history steadily held its way, a crowd of extraordinary little books accompanied and diversified it. Sometimes they were expanded versions of its episodes, sometimes what may be called commentaries or companion volumes. In some of the best of them natural science, a new subject with Michelet, to which his wife is believed to have introduced him, supplies the text. The first of these (by no means the best) was *Les Femmes de la Révolution* (1854), in which Michelet's natural and inimitable faculty of dithyrambic too often gives way to tedious and not very conclusive argument and preaching. In the next, *L'Oiseau* (1856), a new and most successful vein was struck. The subject of natural history was treated, not from the point of view of mere science, nor from that of sentiment, nor of anecdote, nor of gossip, but from that of the author's fervent democratic pantheism, and the result, though as was to be expected unequal, was often excellent. *L'Insecte*, in the same key but duller, followed. It was succeeded by *L'Amour* (1859), one of the author's most popular books, and not unworthy of its popularity, but perhaps hardly his best. These remarkable works, half pamphlets half moral treatises, succeeded each other as a rule at the twelve months' interval, and the succession was almost unbroken for five or six years. *L'Amour* was followed by *La Femme* (1860), a book on which a whole critique of French literature and French character might be founded. Then came *La Mer* (1861), a return to the natural history class, which considering the powers of the writer and the attraction of the subject is perhaps a little disappointing. The next year (1862) the most striking of all Michelet's minor works, *La Sorcière*, made its appearance. Developed out of an episode of the history, it has all its author's peculiarities in the strongest degree. It is a nightmare and nothing more, but a nightmare of the most extraordinary verisimilitude and poetical power.

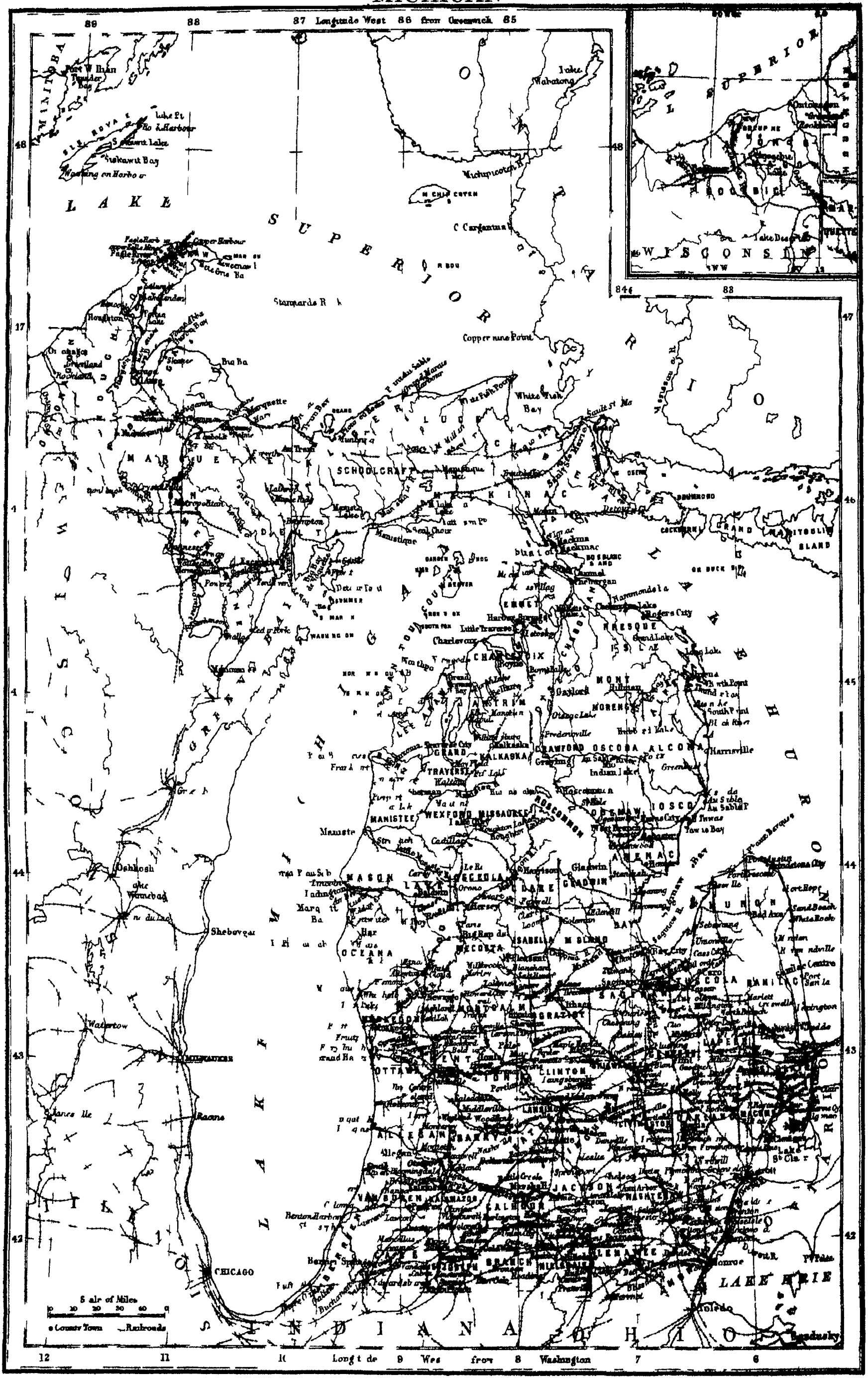
This remarkable series, every volume of which was at once a work of imagination and of research, was not even yet finished, but the later volumes exhibit a certain falling off. The ambitious *Bible de l'Humanité* (1864), an historical sketch of religions, has but little merit. In *La Montagne* (1868), the last of the natural history series, the tricks of staccato style are pushed even farther than by Victor Hugo in his less inspired moments, though—as is inevitable in the hands of such a master of language as Michelet—the effect is frequently grandiose if not grand. *Nos Fils* (1869), the last of the string of smaller books published during the author's life, is a tractate on education, written with ample knowledge of the facts and with all Michelet's usual sweep and range of view, but with visibly declining powers of expression. But in a book published posthumously, *Le Banquet*, these powers reappear at their fullest. The picture of the industrious and famishing populations of the Riviera is (whether true to fact or not) one of the best things that Michelet has done. To complete the list of his miscellaneous works, two collections of pieces, written and partly published at different times, may be mentioned. These are *Les Soldats de la Revolution* and *Legendes Democratiques du Nord*.

The publication of this series of books, and the completion of his history, occupied Michelet during both decades of the empire. He lived partly in France, partly in Italy, and was accustomed to spend the winter on the Riviera, chiefly at Hyeres. At last, in 1867, the great work of his life was finished. As it is now published it fills nineteen volumes. The first of these deals with the early history up to the death of Charlemagne, the second with the flourishing time of feudal France, the third with the 13th century, the fourth, fifth, and sixth with the Hundred Years' War, the seventh and eighth with the establishment of the royal power under Charles VII. and Louis XI. The 16th and 17th centuries have four volumes apiece, much of which is very distantly connected with French history proper, especially in the two volumes entitled *Renaissance* and *Réforme*. The last three volumes carry on the history of the 18th century to the outbreak of the Revolution. The characteristics which this remarkable history shares with Michelet's other works will be noted presently. At present it may be remarked that, as the mere division of subjects and space would imply, it is planned on very original principles. Michelet was perhaps the first historian to devote himself to anything like a picturesque history of the Middle Ages, and his account is still the most vivid though far from the most trustworthy that exists. His inquiry into manuscript and printed authorities was most laborious, but his lively imagination, and his strong religious and political prejudices made him regard all things from a singularly personal point of view. Circumstances which strike his fancy, or furnish convenient texts for his polemic, are handled at inordinate length, while others are rapidly dismissed or passed over altogether. Yet the book is undoubtedly the only history of France which bears the imprint of genius, and in this respect it is not soon likely to meet a rival.

Uncompromisingly hostile as Michelet was to the empire, its downfall and the accompanying disasters of the country once more stimulated him to activity. Not only did he write letters and pamphlets during the struggle, but when it was over he set himself to complete the vast task which his two great histories had almost covered by a *History of the Nineteenth Century*. He did not, however, live to carry it further than Waterloo, and the best criticism of it is perhaps contained in the opening words of the introduction to the last volume—"L'âge me presse." The new republic was not altogether a restoration for Michelet, and his professorship at the Collége de France, of which he contended that he had never been properly deprived, was not given back to him. He died at Hyeres on the 9th of February 1874, and an unseemly legal strife between his representatives took place as to his funeral.

The literary characteristics of Michelet are among the most clearly marked and also among the most peculiar in French literature. A certain resemblance to Lamennais has been already noted, and to this may be added an occasional reminiscence of the manner of Bossuet. But in the main Michelet even in the minor details of style is quite original and individual. His sentences and paragraphs are as different as possible in construction and rhythm from the orderly architecture of French classical prose. A very frequent device of his (somewhat abused latterly) is the omission of the verb, which gives the sentence the air of a continued interjection. Elsewhere he breaks his phrase, not finishing the regular clause at all. In these points and many others the resemblance to his contemporary Carlyle is very striking, and, different as were their points of view, their manners of seeing were by no means unlike. History to Michelet is always picturesque, it is a series of tableaux. Allusion has been already made to the singular per-

MICHIGAN



Piqe

spective in which these tableaux are drawn, a perspective so strange that a reader unacquainted with the actual size and relation of the objects represented is certain to be deceived. Nothing indeed is further from Michelet's purpose than deceit. Although a strong republican, an ardent anti-sacerdotalist, and a patriot of fanatical enthusiasm, he is always scrupulously fair as far as he understands what he is doing. For instance, his hatred for England and Englishmen is one of the most comically intense passions in literature. He is never tired of exclaiming against their diabolical pride, their odious jealousy of France, their calculating covetousness, and so forth. In his excited imagination the long drama of European history is a kind of conflict of Ormuzd and Ahriman, in which France, it is needless to say, plays the first part and England the second. Yet he is never unfair to English fortitude and coolness, never (after the childish fashion of some of his countrymen) slurs over English victories, and often expresses genuine admiration (mixed, it is true, with a shudder or two of aversion) for the masterful ways and constantly advancing prosperity of the English people. So with all his dislike to the priesthood, he never is chary of praise to pope or monk whenever it can fairly be given, and, with all his republicanism, he is never weary of worshipping the heroism of a great king. But his poetical fashion of dealing with events, his exaggeration of trivial incidents into great facts of history, his fixed ideas, especially in reference to the intellectual and social condition of mediæval times, the evils of which he enormously exaggerates, and his abiding prejudices of a general kind combine to distort his accounts in the strangest fashion. A laborious person might pick out of contemporary authors a notable collection of erroneous views of which Michelet is not so much the author as the suggester; for it is when his brilliant exaggerations are torn from their context and set down in some quite other context as sober gospel that they are most misleading to those who do not know the facts, and most grotesque to those who do. This is especially the case in regard to literature. Michelet began his great work too early to enjoy the benefit of the resurrection of old French literature which has since taken place, and though his view of that literature partakes of the amorous enthusiasm which colours his view of everything French, it is astoundingly incorrect in detail. The most remarkable passage of all perhaps is the passage in his *Renaissance* relating to Rabelais, Ronsard, and Du Bellay, a passage so widely inconsistent not only with sound criticism but with historic fact that the author (a very rare thing with him) makes a kind of half apology for it elsewhere. Of the work of the age of chivalry proper, the chansons de gestes, the Arthurian romances, the early lyrics and dramas, he evidently knew but little, and chose to subordinate what he did know to his general theories of the time. Even much later his praise and blame, though transparently honest, are quite haphazard. Unless, therefore, the reader be gifted with a very rare faculty of applying the grain of salt to what he reads, or unless he be well acquainted with the actual facts before coming to Michelet's version of them, he will almost certainly be misled. But despite this grave drawback (which attends all picturesque history) the value of Michelet merely as an historian is immense. Not only are his separate tableaux, the wonderful geographical sketch of France in the beginning of the book, the sections devoted to the Templars, to Joan of Arc, to the Renaissance, to the Camisards, almost unparalleled, but the inspiriting and stimulating effect of his work is not to be surpassed. If his reconstruction is often hazardous and conjectural, sometimes definitely and demonstrably mistaken, and nearly always difficult to adjust entirely to the ascertained facts, it is always possible in itself, always instinct with genius, and always lifelike. There are no dead bones in Michelet; they are, if anything, only too stirring and lively. These criticisms apply equally to the minor books, though these are necessarily fuller of the author's somewhat wearisome propaganda and less full of brilliantly painted facts. The great fault of Michelet, as of not a few other modern authors, is the comparatively improvised and ephemeral character of too much of his work. His immense volume is, much of it, mere brilliant pamphleteering, much more mere description, equally brilliant but equally liable to pass. Nevertheless he is (especially in French, the language *par excellence* of measured and academic perfection) so characteristic and singular a figure in his turbid eloquence and fitful flashing insight that he is never likely to lose a place, and a notable one, in literary history.

Almost all Michelet's works, the exceptions being his translations, compilations, &c., are published in uniform size and in about fifty volumes, partly by Marpon and Flammarion, partly by Calmann Levy. (G. SA.)

MICHELL, JOHN, an eminent English man of science of the 18th century. He received his university education at Queen's College, Cambridge. His name appears fourth in the Tripos list for 1748–49, and in 1755 he was moderator in that examination. He was a fellow of his college, and became successively Woodwardian professor of geology (in 1762) and rector of Thornhill in Yorkshire. He was elected a member of the Royal Society in the same year as Henry Cavendish (1760). He died in 1793. In 1750 he published at Cambridge a small work of some eighty pages, entitled *A Treatise of Artificial Magnets, in which is shown an easy and expeditious method of making them superior to the best natural ones*. Besides the description of the method of magnetization which still bears his name, this work contains a variety of acute and accurate magnetic observations, and is particularly distinguished by a lucid exposition of the nature of magnetic induction. He is now best known as the original inventor of the torsion balance, which afterwards became so famous in the hands of its second inventor Coulomb. Michell described it in his proposal of a method for obtaining the mean density of the earth. He did not live to put his method into practice, but this was done by Henry Cavendish, who made, by means of Michell's apparatus, the celebrated determination that now goes by the name of Cavendish's experiment (*Phil. Trans.*, 1798).

Michell's other contributions to science are:—"Conjectures concerning the Cause and Observations upon the Phenomena of Earthquakes," *Phil. Trans.*, 1760; "Observations on the Comet of January 1760 at Cambridge," *Ib.*, 1760; "A Recommendation of Hadley's Quadrant for Surveying," *Ib.*, 1765; "Proposal of a Method for measuring Degrees of Longitude upon Parallels of the Equator," *Ib.*, 1766; "An Inquiry into the Probable Parallax and Magnitude of the Fixed Stars," *Ib.*, 1767; "On the Twinkling of the Fixed Stars," *Ib.*, 1767; "On the Means of Discovering the Distance, Magnitude, &c. of the Fixed Stars," *Ib.*, 1784.

MICHELOZZI, MICHELOZZO (1391–1472?), was a Florentine by birth, the son of a tailor, and in early life a pupil of Donatello. He was a sculptor of some ability in marble, bronze, and silver. The statue of the young St John over the door of the Duomo at Florence, opposite the Baptistery, is by him, and he also made the beautiful silver statuette of the Baptist on the altar frontal of San Giovanni. Michelozzi's great friend and patron was Cosimo I dei Medici, whom he accompanied to Venice in 1433 during his short exile. While at Venice, Michelozzi built the library of San Giorgio Maggiore, and designed other buildings there. The magnificent Palazzo dei Medici at Florence, built by Cosimo, was designed by him; it is one of the noblest specimens of Italian 15th-century architecture, in which the great taste and skill of the architect has combined the delicate lightness of the earlier Italian Gothic with the massive stateliness of the Classical style. With great engineering skill Michelozzi shored up, and partly rebuilt, the Palazzo Vecchio, then in a ruinous condition, and added to it many important rooms and staircases. When, in 1437, through Cosimo's liberality, the monastery of San Marco at Florence was handed over to the Dominicans of Fiesole, Michelozzi was employed to rebuild the domestic part and remodel the church. For Cosimo I he designed numerous other buildings, mostly of great beauty and importance. Among these were a guest house at Jerusalem, for the use of Florentine pilgrims, Cosimo's summer villa at Careggi, and the strongly fortified palace of Catagiuolo in Mugello. For Giovanni dei Medici, Cosimo's son, he built a very large and magnificent palace at Fiesole. In spite of Vasari's statement that he died at the age of sixty-eight, he appears to have lived till 1472. He is buried in the monastery of San Marco, Florence. Though skilled both as a sculptor and engineer, his fame chiefly rests on his architectural works, which claim for him a position of very high honour even among the greatest names of the great 15th-century Florentines.

MICHIGAN, one of the States of the American Union, situated in the region of the great lakes. It lies between 41° 42′ and 47° 32′ N. lat., and 82° 24′ and 90° 31′ W. long., the centre of the State being 670 miles north of west from New York, the nearest point on the seaboard. The area is 58,915 square miles. The State consists of two natural divisions, known as the Upper and the Lower Peninsula. The Upper or Northern Peninsula is bounded on the N., E., and S. by Lakes Superior, Huron, and Michigan, and on the W. by the river St Mary and the State of Wisconsin. The Lower Peninsula is bounded on the W., N., and E. by Lakes Michigan, Huron, St Clair, and Erie and the St Clair and Detroit rivers, and on the S. by the States of Ohio and Indiana. The general contour of the Lower Peninsula approaches that of a horse shoe, with an average width of about 200 miles from east to west and a length of about 300 miles from north to south. Its surface gradually rises in gentle undulations from the surrounding lakes to an elevation of about 400 feet above Lake Huron, no point reaching an altitude of more than 600 feet. The Upper Peninsula is much more rugged in contour and surface, at some points reaching an elevation of about 1100 feet. The territory was originally covered with forests, with only here and there a small open prairie. It abounds in fine inland lakes, with areas varying from a few acres to several miles. The rivers are not large enough to be navigable, but they afford ample water power, and are particularly valuable for floating down the logs of the lumbering districts. The coast line of the State is not less than about 1600 miles in length, and along the whole of this distance vessels of 2000 tons may pass without losing sight of land.

Geological Formation.—The Lower Peninsula occupies the central part of a great basin, the borders of which extend to the east as far as London, Ontario, and to the west as far as Madison, Wisconsin. Within these limits the traveller starting in any direction from the centre of the State encounters successively the outcropping edges of older and older strata. The whole series has been likened to a nest of wooden dishes, it embraces not only the Laurentian and Huronian systems but also the numerous groups that go to make up the Silurian, the Devonian, the Carboniferous, and the Quaternary systems. These several formations are covered almost universally with a drift of finely comminuted and triturated rock, borne thither by moving glaciers and floating icebergs, or washed to its present position by currents of water, while the surface was still submerged. This loose material varies in thickness, sometimes extending to a depth of 200 or 300 feet. While the lower formations contain almost inexhaustible deposits of copper, iron, gypsum, and salt, the surface soil is pre eminently fertile, uniting all the mineral constituents necessary for the most luxuriant growth of plants. There are limited areas of light and somewhat sterile drift soil, but even these have shown themselves under proper treatment to be capable of yielding a rich vegetation. For the most part the drift soil is composed of a mixture of clay with sand and gravel. It is easily cultivated, is retentive of moisture, and is sufficiently porous to prevent the injury of crops by excessive rains.

Climate and Natural Products.—The mean temperature of Lansing, the capital of the State, as determined by observations extending through eighteen years, is 46.71 Fahr., or about the same as that of Berlin. During the summer months the mean temperature is nearly the same as that of Vienna, in the winter it is nearly that of Stockholm. The annual rainfall during the eighteen years previous to 1882 was about 31 inches. This is very evenly distributed throughout the year, though a little more than half the amount falls in the five months from May to October. The average snowfall in the centre of the State is about 4 feet, though it is seldom that more than 12 inches lie on the ground at any one time. The winter temperature is much modified by the open water of the adjacent lakes. The severe winds are commonly from the west and north west, but in sweeping across the open waters of Lake Michigan they are so far softened as to make the climate much milder than that found in the same latitude on the western side of the lake. This peculiarity is specially favourable to the growth of fruits. Peaches are grown successfully along the 45th parallel, and figs thrive in the open air in lat. 42½°. The modifying influence of the lake winds also gives great variety to the flora. The predominant woods are oak, maple, beech, elm, ash, cherry, hickory, walnut, basswood, and pine. All these grow luxuriantly in the vast forests of the State, and afford an abundant supply of the best timber. There are 165 species of trees and shrubs indigenous to Michigan, and the entire flora of the State makes a list of 1634 species.

Cereals and Fruits.—The most important crop of Michigan is wheat, and the average yield per acre, as shown by the latest census, is greater than that of any other State in the Union. The acres sown in 1879 were reported as 1,822,749, and the amount produced as 35,532,543 bushels. These figures show that Michigan is fourth in rank of the wheat producing States, the number of bushels grown being exceeded by the crops of Illinois, Ohio, and Indiana. In 1879 the yield in bushels of the other principal cereals is shown by the following figures:—Indian corn, 32,461,452; oats, 18,190,793; barley, 1,204,316; rye, 294,918; buckwheat, 413,062; clover seed, 313,063; pease, 538,332. The crop of potatoes in the same year was 8,025,475 bushels, and the hay amounted to 1,051,115 tons. Of the fruits grown in the State apples are the most important, and these are believed to be unsurpassed in excellence in any country in the world. The sales in 1880 were 1,834,936 bushels, a considerable quantity going to the markets of Europe. Next in importance is the peach crop, annually gathered from more than fifty of the counties of the State. In 1880 the peach orchards were reported as covering 12,908 acres, and the fruit sold as amounting to 413,418 bushels. The long coast line of Lake Michigan affords easy access to market even for the most perishable fruits. Besides the facilities thus afforded, the railroads that now thread the State, with an aggregate length in March 1882 of 4332 miles, afford abundant means of rapid transportation. As the fruit belt extends from north to south more than 200 miles, the danger of disastrous competition in the markets is obviated by prolongation of the season of ripening. At the meeting of the State Horticultural Society held in 1881 it was reported that the average value of the peach crop per acre was above $125. The ten volumes of the *Transactions* of the State Horticultural Society published since its organization in 1870 show that the development of fruit culture within the last decade has been much more rapid than in any other State.

Lumber.—The timber produce in Michigan is of superior quality, and the amount is so great that about two thirds of the best lumber sold in New York, Philadelphia, and Boston go out from its mills. The logs are borne along the lakes, rivers, and small watercourses to the booms of mills situated at convenient points, where the lumber is sawed and shipped for the different markets of the world. Of these manufacturing districts those known as the Saginaw, the Grand River, and the Muskegon valleys are the most important. The Saginaw receives the waters of the Tittabawasse, the Cass, the Flint, the Shiawasse, the Bad, the Pine, the Chippewa, the Tobacco, and their numerous tributaries, draining a vast region that still yields an undiminished supply of pine. The forests of the western parts of the State are easily accessible by the Grand River and its tributaries, while those still farther north find a natural outlet through the numerous streams that flow into Lake Michigan. On the banks of these watercourses are some of the largest and finest mills of the world In 1854, when the first effort was made to collect statistics of this industry, it was found that there were only sixty one mills in operation, and that the entire annual product was only 108,000,000 feet Eighteen years later, in 1872, it was estimated that the annual product was not less than 2,560,000 feet of oak, 12,700,000 of staves, 300,000,000 lath, 400,000,000 shingles, and 2,500,000,000 of sawed pine The number of saw mills had already reached about 1500, the number of persons employed 20,000, and the capital represented $25,000,000 In 1881 the manufacture of pine lumber amounted to 3,919,500,000 feet, the value of which exceeded $60,000,000 The aggregate value of the forest products of the State was estimated in 1881 to have reached more than $1,000,000,000 *Forestry Bulletin*, No 6, issued December 1, 1881, estimated the amount of standing white pine of merchantable quality at 35,000,000,000 feet, and the amount of standing hard wood at 700,000,000 cords Besides these amounts, the same authority estimates the amount of hemlock at 7,000,000,000 feet, with 7,000,000 cords of bark, and an aggregate of 70 000,000 of cedar and tamarack It is probable that before many years the hard wood produced by the State will approach in value the figures representing the value of the pine now sent to the markets of the world It is probable that Michigan for many years to come will maintain its precedence as a lumber producing State

Mineral Resources —Of the mineral products of Michigan the most important is iron As early as 1842 the report of the first State geologist, Dr Douglas Houghton, called attention to the presence of hæmatite ore, though for a considerable time after this it was not found in such quantities as to make it certain that mining could be made profitable Before 1860, however, it became known that iron in the Upper Peninsula not only existed in vast quantities, but also that it was of superior quality From that time iron mines were rapidly developed, until in 1881 they had come to exceed in value, though not in amount, even the products of Pennsylvania In 1880 the product was 1,834,712 tons, with a value at the mines of $6,034,648, as against the yield in Pennsylvania of 2,185,675 tons, with a value of $5,517,079 The product of Michigan in 1882 was 2,948,307 tons of ore, with a market value of about $25,000,000 The Michigan minerals are of extraordinary richness,—62 9 per cent being the average of the first class ores while the furnace books often show a much higher yield

Next in importance to the iron mines are those of copper These are also situated in the Northern Peninsula in the mountain range of trappean rocks which crown the point of land extending northwards into Lake Superior This secondary peninsula or cape, known as Keweenaw Point, rises to an average height of about 600 feet above the lake, the highest pinnacles reaching nearly double that altitude This point contains what are believed to be the richest copper mines ever discovered, the metal is not found as an ore, but as virgin copper almost chemically pure It has only to be separated from its rocky matrix, when it is ready for the market The largest of the copper mines, that at Calumet, has built up an industry which employs 2000 men, and its total product of refined copper in 1882 was no less than 50,770,719 ℔, or one eighth of the annual production of copper in the world In quality the copper of the Lake Superior district is such that it commands the highest price at home and abroad Its tenacity is remarkable, and therefore it is eagerly sought after for cartridges by all the great military powers In 1882 the copper mines paid dividends amounting to $2,900,000,—making an aggregate of $28,248,000 since they were opened

Within a few years the salt-works of Michigan have also come to exceed those of any other State in the Union The first well was sunk in 1859-60, but in 1882 the production was found to have exceeded that of the famous works in New York, and to have amounted in that year to no less than 3,204,921 barrels The extraordinary development of this industry is due to several causes A careful system of inspection by State authority has kept its salt unsurpassed in purity The salt basin is not only accessible by navigable waters, so as to have the advantage of cheap transportation, but the wells are situated in the great lumber producing districts, and the manufacture is thus carried on at very small expense, in connexion with the saw mills The power is furnished by the same engines, the exhausted steam is used for the evaporation of brine during the day, and during the night evaporation is still carried on by means of refuse wood and saw dust, while the staves for barrels are made from rejected timber By this system the best quality of salt is obtained at a minimum expense The chief reservoir of salt is the series of sandstones and shales constituting the Waverly group This salt producing rock covers no less than about 8000 square miles, and it is safe to presume that the supply is inexhaustible The average depth of the wells is about 800 feet, but in some localities wells sunk to nearly 2000 feet have been remunerative Important salt works have recently been developed in the western part of the State

There are also certain other minerals of considerable importance Deposits of gypsum, easily accessible, practically inexhaustible in quantity, and superior in quality, are found in several localities both in the eastern and in the western parts of the Lower Peninsula In the outskirts of Grand Rapids the deposit crops out at the surface, and at an average depth of from 40 to 70 feet extends over an area of 10 or 12 square miles The rock is easily quarried, and is either ground for use as a fertilizer or calcined into plaster of Paris The deposits of coal are supposed to cover about 8000 square miles, but as yet the product at any one point has not been very considerable In quality the coal is highly bituminous and is not sufficiently pure to be useful for smelting or for the manufacture of gas For these reasons the stock of coal in the State is practically untouched If future explorations and experiments should make these deposits available, a new era in the manufacture of iron will be the result At present the coal for smelting the Lake Superior ores is brought chiefly from Ohio and Pennsylvania Quarries of limestone and of sandstone have been opened in various parts of the State The brown stone of the Upper Peninsula is of excellent quality, and is capable of receiving a high finish The supply is inexhaustible and the accessibility of the quarries by water gives promise of a thriving industry The grindstones taken from the Huron county quarries are of superior quality, and the slates found in unlimited quantities on the shores of the Huron Bay are unsurpassed in point of durability and colour Clays and sands of commercial value are found in great abundance Though the manufacture of glass is yet in its infancy sands in large quantities have been discovered in Monroe county suitable for the manufacture of plate glass of excellent quality Brick and tile clays are found in all parts of the State Though native silver has been found in small quantities in the Upper Peninsula the systematic mining of this metal has not yet been carried on with successful results The *Report* of the commissioner of mineral statistics for 1882 shows that, except as to coal Michigan is the foremost of all the States in mineral wealth

Fisheries —The geographical position of Michigan explains the fact that its fresh water fisheries are the most productive in the United States The most important varieties of fish are lake trout, sturgeon, bass, pickerel, herring, brook trout grayling, and white fish General laws for the protection of fish have been passed, and a fish commission has been maintained for some years for the purpose of propagating the best varieties and planting them in waters adapted to their natural development Up to the close of 1880 the commissioners had planted about 80,000,000 young white fish, 1,000,000 silver eels 1,000,000 lake trout 2 000,000 salmon, and 500 000 brook trout, besides smaller numbers of shad, grayling, pike and bass Excellent results have followed, especially in the multiplication of white fish, salmon and eels In 1879 the total 'take' was 24 013 100 ℔ of which 12,902 250 ℔ were white fish, the most valuable lake fish known to epicures and to commerce During winter large quantities preserved by freezing are taken to Eastern markets, where they are readily sold at a high price

Educational Institutions —As early as 1785 the law of congress which provided for the sale of lands north of the Ohio river reserved for the support of public schools ' section 16 of each township This fundamental law devoted to educational purposes one thirty sixth of all the lands of that vast domain known as the north western territory The "ordinance of 1787, by which this territory was organized further provided that "schools and the means of education shall for ever be encouraged In 1826 this congressional action was supplemented by a grant to Michigan of two townships of land for the founding and support of a university When Michigan became a State in 1837, its educational policy took definite form The constitution provided, not only that the grant of "section 16 should be devoted exclusively to the support of schools of the primary grade, but also that the State and not each township should be the custodian of the lands so appropriated The constitution expressly provided that the proceeds from the sale of school lands should be held by the State as a perpetual fund the interest of which should be annually applied to the support of primary schools The lands devoted to school purposes in Michigan under these provisions amounted to 1,077 209 acres, of which, in September 1881, 675 000 acres had been sold On the sum realized by these sales, $3,095 679, the State pays interest at 7 per cent, and the resulting income amounting to $216 645, is annually distributed to the schools This source is supplemented from local taxes, so that in 1881 the total sum realized from all sources for the primary schools was $3 644,778

The schools organized under State law are known as graded and ungraded In the small districts where the schools are under the charge of but one or two teachers grading is impracticable Of ungraded districts there were in 1881 6120 attended by 219 570 children, while the graded schools were 404 in number, with an attendance of 152 043 The school census includes all children between the ages of five and twenty amounting in 1881 to 518 317, of whom there was an average attendance of 391 401 To all children of school age the public schools are free though a fee may be required for advanced studies in the high schools The immediate administration of the schools is entrusted to school officers elected annually by the tax payers of the individual districts The State constitution requires that a free school shall be in session at least three months of every year in each district In districts of more than 30 and less than 800 children the law requires at least five months of school while in districts of more than 800 children the session must be not less than nine months in length In the graded schools the division is into primary schools grammar schools, and high schools each of these divisions retaining the scholar ordinarily four years At the end of the course the student is ready for the university to which, under certain restrictions provided by the university itself he is admitted on diploma from the high school The university of Michigan, situated at Ann Arbor was first opened for instruction in 1841 It now 1883 consists of the department of literature science and the arts the department of medicine, the department of law the college of homœopathic medicine, the school of pharmacy, the college of dental surgery, and the school of political science Connected with the medical departments are the State hospitals In 1881-82 there were 86 officers of instruction and 1 34 students The total income for the year 1879 80 from Federal grant State grants and fees was $231,359 The general control of the university is placed in the hands of eight regents elected by popular suffrage at the biennial spring elections two regents being chosen at each election The normal school situated at Ypsilanti and generously supported by the State may be said to complete the school system

Charitable and Reformatory Institutions —A school for the deaf, dumb, and blind instituted under an Act passed in 1848, is situated at Flint, about 60 miles north west of Detroit in February 1882 it had 249 pupils In 1879 a distinct school for the training of the blind was established at Lansing The "State public school for dependent and neglected children" is devoted to the systematic education of such children as otherwise would have to be maintained in the county poorhouses The pupils are divided into "families" of about thirty each, and are cared for in separate cottages, each cottage being under the charge of a "cottage manager The school receives dependent children of sound health, and free from contagious disease, and it is made the duty of the officers havin charge of the poor to send all such children between the ages o three and twelve to it This institution, the pioneer of its kind. and one of the most useful of charitable schools, is situated at Coldwater, 132 miles south west of Detroit In February 1882 ther were 320 children and 21 officers and teachers The "Reform School at Lansing is designed to reclaim juvenile offenders wh have been convicted of some offence A farm of 224 acres connecte with the school is, in considerable part, tilled by the boys Th number of inmates in February of 1882 was 325 A similar schoo at Adrian has recently been instituted for girls There are Stat asylums for the insane at Kalamazoo (715 patients) and Pontia (499 patients) The legislature of 1881 provided for the establishment of an additional asylum in one of the northern counties of th Lower Peninsula

Population —In 1837 the State had 174,647 inhabitants Th numbers according to the different census returns from 1840 ar given in the following table —

Census	Total	Males	Females	Density per Square Mile
1840	212 267	113 788	98 479	3 77
1850	397 654	209 897	187 757	7 07
1860	749 113	394 694	354 419	12 11
1870	1 184 059	617 745	566 314	20 01
1880	1 636 937	862 678	[illegible]	27 80

At the last census 388,508 of the inhabitants were of foreign birth, 97,346 being natives of the United Kingdom 89 085 Germans, an 16,445 Scandinavians In point of population the State, whic was twenty third in 1840, now stands ninth in the Union

The following are the principal cities in the State, with population at the census of 1880 —Detroit, 116,340, Grand Rapids City 32,016, Bay City, 20,693, East Saginaw City, 19,016, Jackso City, 16,105, Muskegon City, 11,262 Saginaw City, 10,525, Por Huron, 8883, Flint City, 8410, Lansing (the State capital) 8319, Ann Arbor, 8061, Adrian City, 7849, Battle Creek, 7063 Manistee 6930, West Bay City, 6397, Alpena City, 6153 Ishpeming 6039

History and Government —The State of Michigan is part of th territory that was first settled by the French, and until the fall o Canada into the hands of the British after the middle of the 18t century was under the government of New France The territor was explored by Jesuit missionaries in the 17th century, but although it was known at an early period that the lands wer of exceptional excellence, very little progress was made in developing the resources of the territory until after the completion o the first half century of the American Union The surveyor employed by the general government to inspect the lands an report as to their fitness for settlement by the soldiers of the wa of 1812 appear to have derived their impressions almost exclusivel from the low lands in the south eastern corner of the territory Th report, accordingly, was not favourable, and consequently the tid of immigration that had already begun to set in flowed steadil past Michigan into the territories farther west It was largely fo this reason that the early development of Indiana, Illinois, Iowa and Wisconsin was somewhat more rapid than that of Michigan But gradually the false impressions concerning the soil and climat were dispelled, and within the past few years the increase of th population and the growth of wealth have been very rapid In 1851 the valuation of the State for purposes of taxation (whi excludes much valuable property) was $30,976,270, in 1861, $172,055,808, in 1871, $630,000,000 at 1881, $810,000,000 The State constitution, adopted in 1837 at the time of admissio to the Union, has been modified in some minor particulars, but i most respects it remains unchanged The governor is elected fo two years, with no restriction as to re election The legislatur meets biennially in the first week of January and usually continue in session till May The supreme court consists of four judges chosen by popular vote for terms of eight years, one being electe every second year Judges have been so frequently re elected that the office may be said to be practically a permanent one, with provision for termination in case of need The State is divided int twenty two judicial districts, in each of which a circuit court sits fo the trial of causes of original jurisdiction and of causes appeale from the justice courts The judges of the circuit courts are als elected by popular suffrage On political questions voting is ope to all naturalized citizens of the male sex more than twenty-one years of age unless prevented by some natural disqualification A school meetings the right of suffrage is extended so as to include tax payers of either sex

Authorities —Frederick Morley, *Michigan and its Resources*, compiled unde authority of the State, 2d ed Detroit 1882 *Walling's Atlas of Michigan, with an Account of the Topography, Climate and Geology of the State*, by Alex Winchell LL D James V Campbell *Outlines of the Political History o Michigan Reports of the Secretary of the State Pomological Society of Michiga from 1871 to 1880 Report of the Commissioner of Education for 1880 Fort*

Annual Report of the Superintendent of Public Instruction of the State of Michigan for the year 1881; *Reports of the Geological Survey of the State of Michigan*, 869-80, 4 vols.; *Special Report of Commissioner of Mineral Statistics*, March 1883; *Forestry Bulletins* for 1881. (C. K. A.)

MICHIGAN, LAKE. See ST LAWRENCE.

MICHIGAN CITY, a town of the United States, in Laporte county, Indiana, on the south-east shore of Lake Michigan, 40 miles east-south-east of Chicago. As a lake-port and a junction for several railroads, it is a place of considerable prosperity. It is the largest lumber market in the State, and one of the largest in the west, and has numerous manufacturing establishments. The northern State prison (with 577 convicts at the close of 1880) is one of the principal buildings. The population increased from 3985 in 1870 to over 10,000 in 1883.

MICHMASH (מכמש, מכמס), the scene of one of the most striking episodes in Old Testament history (1 Sam. xiv., comp. vol. xii. p. 403), was a place in Benjamin, about 9 Roman miles north of Jerusalem (*Onom.*, ed. Lag., p. 280). Though it did not rank as a city (Josh. xviii. 21 *sq.*), Michmash was recolonized after the exile (Neh. xi. 31), and, favoured by the possession of excellent wheat land (*Mishna*, Men. viii. 1) was still a very large village (Μαχμας) in the time of Eusebius. The modern Makhmas is quite a small place.

The historical interest of Michmash is connected with the strategical importance of the position commanding the north side of the Pass of Michmash, which made it the headquarters of the Philistines and the centre of their forays in their attempt to quell the first rising under Saul, as it was also at a later date the headquarters of Jonathan the Hasmonæan (1 Mac. ix. 73). From Jerusalem to Mount Ephraim there are two main routes. The present caravan road keeps the high ground to the west near the watershed, and avoids the Pass of Michmash altogether. But another route, the importance of which in antiquity may be judged of from Isa. x. 28 *sq.*, led southwards from Ai over an undulating plateau to Michmash. Thus far the road is easy, but at Michmash it descends into a very steep and rough valley, which has to be crossed before reascending to Geba.[1] At the bottom of the valley is the Pass of Michmash, a noble gorge with precipitous craggy sides. On the north the crag is crowned by a sort of plateau sloping backwards into a round-topped hill. This little plateau, about a mile east of the present village of Makhmas, seems to have been the post of the Philistines, lying close to the centre of the insurrection, yet possessing unusually good communication with their establishments on Mount Ephraim by way of Ai and Bethel, and at the same time commanding the routes leading down to the Jordan from Ai and from Michmash itself.

MICKIEWICZ, ADAM (1798-1855), Polish poet, was born in 1798, near Nowogrodek, in the present government of Minsk, where his father, who belonged to the schlachta or lesser nobility, had a small property. The poet was educated at the university of Vilna, but, becoming involved in some political troubles there, he was forced to terminate his studies abruptly, and was ordered to live for a time in Russia. He had already published two small volumes of miscellaneous poetry at Vilna, which had been favourably received by the Slavonic public, and on his arrival at St Petersburg he found himself admitted to the leading literary circles, where he was a great favourite both from his agreeable manners and his extraordinary talent of improvisation. In 1825 he visited the Crimea, which inspired a collection of sonnets in which we may admire both the elegance of the rhythm and the rich Oriental colouring. The most beautiful are *The Storm*, *Bakhchi-serai*, and *Grave of the Countess Potocka*.

In 1828 appeared his *Konrad Wallenrod*, a narrative poem describing the battles of knights of the Teutonic order with the heathen Lithuanians. Here under a thin veil, Mickiewicz represented the sanguinary passages of arms and burning hatred which had characterized the long feuds of the Russians and Poles. The objects of the poem, although evident to many, escaped the Russian censors, and it was suffered to appear, although the very motto, taken from Machiavelli, was significant: 'Dovete adunque sapere come sono duo generazioni da combattere ... bisogna essere volpe e leone.' After a five years' exile in Russia the poet obtained leave to travel; he had secretly made up his mind never to return to that country or Poland so long as it remained under the government of the Muscovites. Wending his way to Weimar, he there made the acquaintance of Goethe, who received him cordially, and, pursuing his journey through Germany, he entered Italy by the Splugen, visited Milan, Venice, and Florence, and finally took up his abode at Rome. There he wrote the third part of his poem *Dziady*, the subject of which is the religious commemoration of their ancestors practised among Slavonic nations, and *Pan Tadeusz*, his longest poem, by many considered his masterpiece. A graphic picture is drawn of Lithuania on the eve of Napoleon's expedition to Russia in 1812. In 1832 Mickiewicz left Rome for Paris, where his life was for some time spent in poverty and unhappiness. He had married a Polish lady, Selina Szymanowska, who became insane. In 1840 he was appointed to the newly founded chair of Slavonic languages and literature in the Collége de France, a post which he was especially qualified to fill, as he was now the chief representative of Slavonic literature, Poushkin having died in 1837. He was, however, only destined to hold it for a little more than three years, his last lecture having been given on the 28th of May 1844. His mind had become more and more disordered under the influence of religious mysticism. His lectures became a medley of religion and politics, and thus brought him under the censure of the Government. A selection of them has been published in four volumes. They contain some good sound criticism, but the philological part is very defective, for Mickiewicz was no scholar, and he is obviously only well acquainted with two of the literatures, viz., Polish and Russian, the latter only till the year 1830. A very sad picture of the declining days of Mickiewicz is given in the memoirs of Herzen. At a comparatively early period the unfortunate poet exhibited all the signs of premature old age; poverty, despair, and domestic affliction had wrought their work upon him. In 1849 he founded a French newspaper, *La Tribune des Peuples*, but it only existed a year. The restoration of the French empire seemed to kindle his hopes afresh; his last composition is said to have been a

of the Crimean war he was sent to Constan-
in raising a regiment of Poles to take service against the Russians. He died suddenly there in 1855, and his body was removed to France and buried at Montmorency.

Mickiewicz is held to have been the greatest Slavonic poet, with the exception of Poushkin. Unfortunately in other parts of Europe he is but little known; he writes in a very difficult language, and one which it is not the fashion to learn. Here we feel the pathos and irony in the expression used by a Polish lady to a foreigner, 'Nous avons notre Mickiewicz à nous.' He is one of the best products of the so-called romantic school. The Poles had long groaned under the yoke of the classicists, and the country was full of legends and picturesque stories which only awaited the coming poet to put them into shape. Hence the great popularity among his countrymen of his ballads, each of them being connected with some national tradition. Besides *Konrad Wallenrod* and *Pan Tadeusz*, attention may be called to the poem *Grazyna*, which describes the adventures of a Lithuanian chieftain against the Teutonic knights. It is said by Ostrowski to have inspired the brave Emilia Plater, who was the heroine of the rebellion of 1830, and after having fought in the ranks of the insurgents found a grave in the forests of Lithuania. A fine vigorous Oriental piece is *Farys*. Very good too are the odes to Youth and to the historian Lelewel; the former did much to stimulate the efforts of the Poles to shake off their Russian conquerors. It is enough to say of Mickiewicz that he has obtained the proud position of the representative poet of his country. Her customs, her superstitions, her history, her struggles are reflected in his works.

---

[1] So Isa. x. 28 describes the invader leaving his heavy baggage at Michmash before pushing on through the p

MICKLE, WILLIAM JULIUS (1734–1788), son of the minister of Langholm, Dumfriesshire, holds a respectable place among the imitative minor poets of the 18th century He wrote a poem on *Knowledge*—carefully versified, pointing a moral on the vanity of intellectual pride—at the age of eighteen, entered into business as a brewer at his father's request and against his own inclinations, soon became bankrupt, went to London on outlook for work as a man of letters, solicited patronage in vain, earned a living hardly by writing for magazines, made some impression in 1765 by "a poem in the manner of Spenser" called the *Concubine* (afterwards *Syr Martyn*), was appointed corrector to the Clarendon Press, and finally took a place among the leading poets of that very barren time by a translation of the *Lusiad* of Camoens into heroic couplets (specimen published 1771, whole work 1775) So great was the repute of the work that when Mickle—appointed secretary to Commodore Johnstone—visited Lisbon in 1779 the king of Portugal gave him a public reception As a translator of Camoens Mickle has been superseded, but he aimed, not at close rendering of the original but at making a poem which should be worthy of a permanent place in English literature This ambition he was not capable of fulfilling, though he had great fluency and vigour It may be doubted whether the fashionable forms which he imitated were the best suited to his natural gifts He shows delight in lively action, a sense of dramatic effect, and, in the *Concubine*, the substance of which might have been conceived by Crabbe, considerable fulness of detail in coarse realistic painting Certainly, if the Scottish poem *There's nae luck aboot the hoose* was Mickle's, he mistook his medium Scott read and admired Mickle's poems in his youth, and, besides founding *Kenilworth* on the ballad of *Cumnor Hall*, was a good deal influenced by him in style Mickle's prose is lively and vigorous

MICROMETER, an instrument generally applied to telescopes and microscopes for measuring small angular distances with the former or the dimensions of small objects with the latter

Before the invention of the telescope the accuracy of astronomical observations was necessarily limited by the angle that could be distinguished by the naked eye The angle between two objects, such as stars or the opposite limbs of the sun, was measured by directing an arm furnished with fine "sights" (in the sense of the "sights" of a rifle) first upon one of the objects and then upon the other, or by employing an instrument having two arms each furnished with a pair of sights, and directing one pair of sights upon one object and the second pair upon the other The angle through which the arm was moved, or, in the latter case, the angle between the two arms, was read off upon a finely graduated arc With such means no very high accuracy was possible Archimedes concluded from his measurements that the sun's diameter was greater than 27 and less than 32 , and even Tycho Brahe was so misled by his measures of the apparent diameters of the sun and moon as to conclude that a total eclipse of the sun was impossible[1] Mæstlin in 1579 determined the relative positions of eleven stars in the Pleiades (*Historia Cœlestis Lucii Baretti*, Augsburg, 1666), and Winnecke has shown (*Monthly Notices R A S*, vol xxxix p 146) that the probable error of these measures amounted to about [illegible]

The invention of the telescope at once extended the possibilities of accuracy in astronomical measurements. The planets were shown to have visible disks, and to be attended by satellites whose distance and position angle relative to the planet it was desirable to measure It became, in fact, essential to invent a "micrometer" for measuring the small angles which were thus for the first time rendered sensible There is now no doubt that William Gascoigne, a young gentleman of Yorkshire, was the first inventor of the micrometer Crabtree, a friend of his, taking a journey to Yorkshire in 1639 to see Gascoigne, writes thus to his friend Horrocks "The first thing Mr Gascoigne showed me was a large telescope amplified and adorned with inventions of his own, whereby he can take the diameters of the sun and moon, or any small angle in the heavens or upon the earth, most exactly through the glass, to a second" The micrometer so mentioned fell into the possession of Mr Richard Townley of Lancashire, who exhibited it at the meeting of the Royal Society held on the 25th July 1667

Gascoigne's micrometer

The principle of Gascoigne's micrometer is that two pointers, having parallel edges at right angles to the measuring screw, are moved in opposite directions symmetrically with and at right angles to the axis of the telescope The micrometer is at zero when the two edges are brought exactly together The edges are then separated till they are tangent to the opposite limbs of the disk of the planet to be measured, or till they respectively bisect two stars, the angle between which is to be determined The symmetrical separation of the edges is produced and measured by a single screw, the fractions of a revolution of the screw are obtained by an index attached to one end of the screw, reading on a dial divided into 100 equal parts The whole arrangement is elegant and ingenious A steel cylinder (about the thickness of a goose quill), which forms the micrometer screw, has two threads cut upon it, one half being cut with a thread double the pitch of the other This screw is mounted on an oblong box which carries one of the measuring edges, the other edge is moved by the coarser part of the screw relatively to the edge attached to the box, whilst the box itself is moved relatively to the axis of the telescope by the finer screw This produces an opening and closing of the edges symmetrically with respect to the telescope axis Flamsteed, in the first volume of the *Historia Cœlestis*, has inserted a series of measurements made by Gascoigne extending from 1638 to 1643 These include the mutual distances of some of the stars in the Pleiades, a few observations of the apparent diameter of the sun, others of the distance of the moon from neighbouring stars, and a great number of measurements of the diameter of the moon Dr Bevis (*Phil Trans*, 1773, p 190) also gives results of measurements by Gascoigne of the diameters of the moon, Jupiter, Mars, and Venus with his micrometer

Delambre gives[3] the following comparison between the results of Gascoigne's measurements of the sun's semi diameter and the computed results from modern determinations —

	Gascoigne	*Conn d Temps*
October 25 (O S)	16 11 or 10	16 10 0
„ 31 „	16 11	16 11 4
December 2 „	16 24	16 16 8

Gascoigne, from his observations, deduces the greatest variation of the apparent diameter of the sun to be 35′, according to the *Connaissance des Temps* it amounts to 32 3[3] These results prove the enormous advance attained in accuracy by Gascoigne, and his indisputable title to the credit of inventing the micrometer

Huygens, in his *Systema Saturnium* (1659), describes a micrometer with which he determined the apparent diameters of the principal planets He inserted a slip of metal, of variable breadth, at the focus of the telescope, and observed at what part it exactly covered the object under examination, knowing the focal length of the telescope and the width of the slip at the point observed, he thence deduced the apparent angular breadth of the object The Marquis Malvasia in his *Ephemerides* (Bologna, 1662) describes a micrometer of his own invention At the focus of his telescope he placed fine silver wires at right angles to each other, which, by their intersection, formed a network of small squares The mutual distances of the intersecting wires he determined by counting, with the aid of a pendulum clock, the number of seconds required by an equatorial star to pass from web to web, while the telescope was adjusted so that the star ran parallel to the wires at right angles to those under investigation [1] In the *Phil Trans*, 1667, No 21, p 373, Auzout gives the results of some measures of the diameter of the sun and moon made by himself, and this communication led to the letters of Mr Townley and Dr Bevis above referred to The micrometer of Auzout and Picard was provided with silk fibres or silver wires instead of the edges of Gascoigne, but one of the silk fibres remained fixed while the other was moved by a screw It is beyond doubt that Huygens independently discovered that an object placed in the common focus of the two lenses of a Kepler telescope appears as distinct and well defined as the image of a distant body, and the micrometers of Malvasia, Auzout, and Picard are the natural developments of this discovery Gascoigne was killed at the battle of Marston Moor on the 2d July 1644, in the twenty fourth year of his age, and his untimely death was doubtless the cause that delayed the publication of a discovery which anticipated, by twenty years, the combined work of Huygens, Malvasia, Auzout, and Picard in the same direction

---

[1] Grant, *History of Physical Astronomy*, p 449

[2] This is an astonishing accuracy when the difficulty of the objects is considered Few persons can see with the naked eye—much less measure—more than six stars of the Pleiades although all the stars measured by Maestlin have been seen with the naked eye by a few individuals of exceptional powers of eyesight

[3] Delambre, *Hist Ast Moderne*, vol ii p 590

As the powers of the telescope were gradually developed, it was found that the finest hairs or filaments of silk, or the thinnest silver wires that could be drawn, were much too thick for the refined purposes of the astronomer, as they entirely obliterated the image of a star in the more powerful telescopes To obviate this difficulty Professor Felice Fontana of Florence (*Saggio del real gabinetto di fisica e di storia naturale*, 1755) first proposed the use of spider webs in micrometers,[2] but it was not till the attention of Troughton had been directed to the subject by Rittenhouse that the idea was carried into practice [3] In 1813 Wollaston proposed fine platinum wires, prepared by surrounding a platinum wire with a cylinder of silver, and drawing out the cylinder with its platinum axis into a fine wire [4] The surrounding silver was then dissolved by nitric acid, and a platinum wire of extreme fineness remained But experience soon proved the superiority of the spider web, its perfection of shape, its lightness and elasticity, have led to its universal adoption

Beyond the introduction of the spider line it is unnecessary to mention the various steps by which the Gascoigne micrometer assumed the modern forms now in use, or to describe in detail the suggestions of Hooke,[5] Wren, Smeaton, Cassini, Bradley, Maskelyne, Herschel, Arago, Pearson, Bessel, Struve, Dawes, &c, or the successive productions of the great artists Ramsden, Troughton, Fraunhofer, Ertel, Simms, Cooke, Grubb, Clarke, and Repsold It will be sufficient to describe those forms with which the most important work has been done, or which have survived the tests of time and experience

Position angles

Before astronomical telescopes were mounted parallactically, the measurement of position angles was seldom attempted Indeed in those days, the difficulties attached to such measures, and to the measurement of distances with the filar micrometer, were exceedingly great, and must have taxed to the utmost the skill and patience of the observer For, on account of the diurnal motion, the direction of the axis of the telescope when directed to a star is always changing, so that to follow a star with an altazimuth mounting, the observer requires to move continuously the two handles which give slow motion in altitude and azimuth

Herschel's instrument

Sir William Herschel was the first astronomer who measured position angles, the instrument he employed is described in *Phil Trans*, 1781 vol lxxi p 500 It was used by him in his earliest observations of double stars (1779 83) but, even in his matchless hands, the measurements were comparatively crude because of the difficulties he had to encounter from the want of a parallactic mounting In the case of close double stars he estimated the distance in terms of the disk of the components For the measurement of wider stars he invented his lamp micrometer, in which the components of a double star observed with the right eye were made to coincide with two lucid points placed 10 feet from the left eye The distance of the lucid points was the tangent of the magnified angles subtended by the stars to a radius of 10 feet This angle therefore, divided by the magnifying power of the telescope gives the real angular distance of the centres of a double star With a power of 460 the scale was a quarter of an inch for every second

The Modern Filar Micrometer

When equatorial mountings for telescopes became more general no filar micrometer was considered complete which was not fitted with a position circle [6] The use of the spider line or filar micrometer became universal the methods of illumination were improved and micrometers with screws of previously unheard of fineness and accuracy were produced These facilities coupled with the wide and fascinating field of research opened up by Sir William Herschel's discovery of the binary character of double stars gave an impulse to micrometric research which has continued unabated to the present time A still further facility was given to the use of the filar micrometer by the introduction of clock work which caused the telescope automatically to follow the diurnal motion of a star and left the observer's hands entirely at liberty [7]

Classification of micrometers

The modern filar micrometer has now assumed forms of five types

Type A.—Micrometers in which there are two webs each movable by a fine screw with a divided head This is the usual English form of filar micrometer

Type B.—Micrometers in which one web is movable by means of a fine screw with a divided head and the other by a screw without a divided head The latter screw in ordinary use is only employed to change the coincidence reading of the two webs for eliminating the errors of the micrometer screw This is the ordinary German form of micrometer as originally made by Fraunhofer and since by Merz and employed by the Struves and other principal Continental astronomers down to the present day

Type C.—A similar form of micrometer to type B except that the coincidence point cannot be changed —there being no second screw to alter the position of the fixed web

Type D.—A micrometer somewhat similar in general construction to form B, except that in addition to means of changing the zero point there is a screw head by which a fine movement can be given to the whole micrometer box, in the direction of the axis of the micrometer screw This is the modern form of micrometer as constructed by Repsold

Type E.—Micrometers fitted with two eye pieces for measuring angles larger than the field of view of an ordinary eye piece

Troughton's filar micrometer.

The micrometer of type A is due to Troughton it is represented in figs 1, 2 3 Fig 1 is a horizontal section in the direction of the axis of the telescope The eye piece *ab* consists of two plano convex lenses *a* *b* of nearly the same focal length and with the two convex sides facing each other. They are placed at a distance apart less than the focal length of *e*, so that the wires of the micrometer, which must be distinctly seen, are beyond *b*.[1] The eye-piece slides into the tube *d*, which screws into the brass ring *cf*, through two openings in which the oblong frame, containing the micrometer slides, passes. The slides are shown in fig. 2, and consist of brass forks *k* and *l*, into which the ends of the screws *o* and *p* are rigidly fitted. The slides are accurately fitted so as to have no sensible lateral shake, but yet so as to move easily in the direction of the greatest length of the micrometer box. Motion is communicated to the forks by female screws tapped in the heads *m* and *n* acting on the screws *o* and *p* respectively. Two pins *q r*, with spiral springs coiled round them, pass loosely through holes in the forks *k l* and keep the bearings of the heads *m* and *n* firmly pressed against the ends of the micrometer box. Thus the smallest rotation of either head communicates to the corresponding slide motion which, if the screws are accurate, is proportional to the amount through which the head is turned. Each head is graduated into 100 equal parts on the drums *u* and *v*, so that, by estimation, the reading can easily be carried to $\frac{1}{1000}$th of a revolution. The total number of revolutions is read off by a scale attached to the side of the box, but not seen in the figure.

---

[1] *Mem Acad des Sciences*, 1717 p 78 sq

[2] In 1782 (*Phil Trans* vol lxxii p 163) Sir W Herschel writes —'I have in vain attempted to find lines sufficiently thin to extend them across the centres of the stars so that their thickness might be neglected It is a matter of regret that Fontana's suggestion was unknown to him

[3] Quekett in his *Treatise on the Microscope* ascribes to Ramsden the practical introduction of the spider web in micrometers The evidence appears to be in favour of Troughton

[4] *Phil Trans*, 1813, pp 114 118

[5] Dr Hooke made the important improvement on Gascoigne's micrometer of substituting parallel *hairs* for the parallel edges of its original construction (Hooke's *Posthumous Works* p 497)

[6] Herschel and South (*Phil Trans*, 1824 part iii p 10 claim that the micrometer by Troughton, fitted to their 5 feet equatorial telescope, is the first position micrometer constructed capable of measuring position angles to 1 of arc

[7] So far as we can ascertain the first telescope of large size driven by clockwork was the 9 inch equatorial made for Struve at Dorpat by Fraunhofer, it was completed in 1825 The original idea appears to be due to Passement (*Mem Acad Paris* 1746 In 1757 he presented a telescope to the king so accurately driven by clockwork that it would follow a star all night long

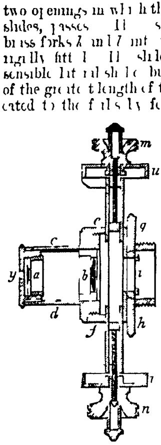


Fig 1

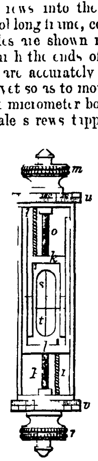


Fig 2

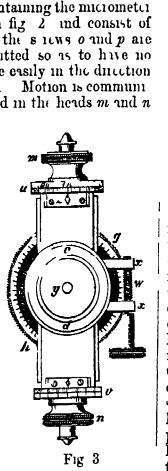


Fig 3

Two spider webs are stretched across the forks, one (*t*) being cemented in a fine groove cut in the inner fork *k*, the other (*s*) in a similar groove cut in the outer fork *l*. These grooves are simultaneously cut *in situ* by the maker with the aid of an engine capable of ruling fine straight lines, so that the webs when accurately laid in the grooves are perfectly parallel. A wire *st* is stretched across the centre of the field perpendicular to the parallel wires. Each movable web must pass the other without coming in contact with it or the fixed wire, and without rubbing on any part of the brass work. Should either fault occur (technically called "fiddling") it is fatal to accurate measurement. One of the most essential points in a good micrometer is that all the webs shall be so nearly in the same plane as to be well in focus together under the highest powers used, and at the same time absolutely free from "fiddling." For measuring position angles a large brass circle *gh* (fig. 3), fixed to the telescope by the screws *a*, has cut teeth on its circumference that receive the teeth of an endless screw *w*, which, being fixed by the arms *x* to the oblong box *mn*, gives the latter a motion of rotation round the axis of the telescope. An index upon this box points out on the graduated circle *gh* the angular rotation of the instrument.

The English micrometer still retains the essential features of Troughton's original construction above described. The later English artists have somewhat changed the mode of communicating motion to the slides by attaching the screws permanently to the micrometer head and tapping each micrometer screw into its slide. Instead of making the shoulder of the screw a flat bearing surface they have given the screw a spherical bearing resting in a hollow cone (fig. 4) attached to the end of the box. The French artists still retain Troughton's form. Simms (Troughton's successor) and Cooke (of York), for symmetry and more effectual elimination of the loss of time" (called by the Germans "todter Gang" and sometimes in English "back lash"), have provided two pins with spiral springs,

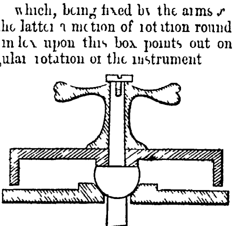


Fig 4

like *q* and *r* (fig. 2), one on each side of the screw which moves each slide.

Grubb of Dublin, with the intention of avoiding the variation of pressure exerted by the spiral springs when the slide is at different distances from the head of the screw, has adopted the following plan. Where the screw enters the slide he has a nut *n* attached to a strong spring *pp* (fig. 5), the pressure of which exerts a constant tension in the axis of the screw, tending to bring the threads into close contact, in opposite directions, with their bearings in the nut *n* and the slide *q*. The pressure of this spring is regulated by the screws *s*, *s*, tapped into the thickened ends of the springs. For maintaining the spherical shoulder of the screw in close and constant pressure on its conical bearing he has attached a conical bearing to the spring *pp* (fig. 6). The pressure of this on the upper part of the spherical shoulder is regulated by the screws *s*, *s*, passing through elongated holes in the spring *pp*, and tapped into the end of the box.

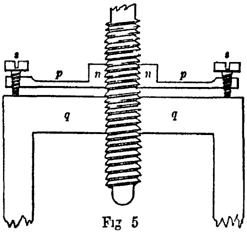


Fig 5

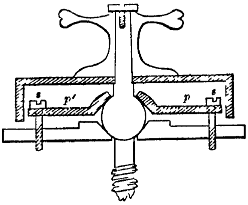


Fig 6

The screws of micrometers are generally made with 50 or 100 threads to the inch. Troughton's method of reading the number of whole revolutions by a silver scale is inconvenient because $\frac{1}{100}$th or even $\frac{1}{50}$th of an inch is too small a quantity to read easily with the naked eye, especially with the faint illumination that it is desirable to use when measuring faint objects. Different methods, including the "comb" (see below) and various kinds of "counters," have been introduced with more or less success; but recently the Repsolds of Hamburg have contrived a plan at once so simple and so efficient that it will be unnecessary to describe those methods which this plan is certain to supersede (see below, type D). Grubb has introduced a modification in the form of the slides with a view to avoid the friction of one slide against the other. On the inner side of the brass plate which forms the bottom of the box (*i.e.* the side opposite to the eye-piece) four V-shaped furrows are placed (fig. 7), and at each end of the slides are projections (fig. 8, end view) which fit into these furrows. The slides are kept down in their places by springs attached to them, which press upon the inner side of the lid of the box.

Fig 7

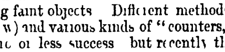


Fig 8

Troughton's mode of giving rotation to the position circle is now abandoned. A much quicker motion in position angle than can be obtained without slow motion is often desirable, since, in observing very close double stars, the uncertainty of each pointing may amount to several degrees in the most accurate measurements. The plan of a pinion working in a toothed wheel is often employed, but that also is too slow. Most modern micrometers are now fitted with a clamp and slow motion screw (see fig. 9 type B). This permits observation of position angles of very close objects by simple rotation of the box with the hand, while the slow motion, after clamping, permits the more delicate movements that are required in measuring the position angle of objects farther apart.

The Cookes and Grubb have for years almost invariably transferred the position circle from the micrometer to the telescope tube. The whole eye end with its focussing arrangements rotates, and its rotation can be measured by a circle attached to the butt end of the tube. There is considerable convenience in this arrangement. One position circle only is required for all the micrometers that may be employed with the instrument, and the orientation of reticulated diaphragms, or the adjustment of the direction of the slit of a spectroscope, may also be accomplished by the same means. But, after a very extended experience of all the various types of existing mountings, the present writer does not hesitate to express a decided preference for a position circle attached to the micrometer and a rigid attachment of the eye end to the telescope tube,—having never seen an eye end attached to a position circle on the butt end of the telescope tube in which, after the wear and tear of a few years, some looseness or shake could not be detected. This is a fatal fault, especially in those delicate observations of difference of declination which have latterly formed so prominent a feature in refined micrometric research. On the other hand, in some good old micrometers at the Royal Observatory, Cape of Good Hope, that are fitted with attached position circles, there is no trace of shake or wear after fifty years of work.

---

[1] This is known as Ramsden's eye-piece, it was made originally by him.

Fraunhofer's filar micrometer.

The micrometer of type B represented in fig 9[1] is the original Merz micrometer of the Cape Observatory, made on Fraunhofer's model. S is the head of the micrometer screw proper, s that of the screw moving the slide to which the so called "fixed web" is attached, s' that of a screw which moves the eye piece E. C is the clamp and M the slow motion in position angle. L, L are tubes attached to a larger tube N; the latter fits loosely on a strong hollow cylinder which terminates in the screw V. By this screw the whole apparatus is attached to the telescope. The nozzles of small lamps are inserted in the tubes L L, for illuminating the webs in a dark field; the light from these lamps is admitted through apertures in the strong hollow cylinder above mentioned (for illumination, see below). In this micrometer the three slides moved by S, s and s' are simple dovetails. The lowest of these slides reposes upon a foundation plate *pp* into one end of which the screw *s* is tapped. In the middle of this slide a stiffly fitting brass disk is inserted to which a small turn table motion may be communicated by an attached arm acted on by two fine opposing screws accessible to the astronomer, and by their means the "fixed wire" may be rendered strictly parallel with the movable wire.

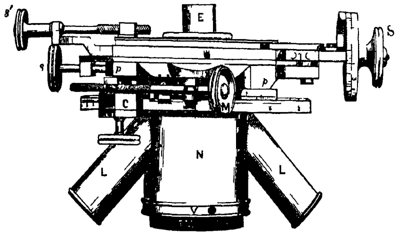


Fig 9

The micrometer screw is mounted on the slide which carries the movable web. Fig 10 shows a plan of this slide; the divided drum of the screw is omitted for sake of clearness. The screw S has a shoulder at *κ*, carefully fitted and ground to a bearing so as to work sweetly in a hole in the very strong spring *σσ*; the other extremity of the screw is formed into a pivot, which fits a hole in the brass piece *ββ*. The end of this pivot—hardened, polished, and slightly rounded—rests on the flat surface of an agate *a*, which is imbedded in the end of the slide, and kept firmly in its place by the brass piece *ββ*. By careful adjustment of the screws *θ*, *θ* sufficient pressure may be left upon *κ* to slightly bend the strong spring *σσ* and thus eliminate all end shake without preventing easy action of the screw. The screw passes at the same time through the bush B (shown in plan and elevation, fig 10) attached to *pp* (fig 9), and there is a fine saw cut, which can be narrowed by the small screw *τ*, to close the bush upon the micrometer screw with a view of preventing "loss of time." The spider web *ω* is cemented on the further side of the thin plate *vvv*, the varnish being applied in the countersunk holes shown by the dotted circles *μ*, *μ*. The slide is countersunk to about half its thickness within the area indicated by *oooo*, in order to allow the adapter of the eye piece to come sufficiently close to the webs. The eye piece was originally moved by a pinion working in a rack *r* (fig 9), but the screw *s* applied by Simms was found by Maclear to be more convenient for the purpose. Beyond this, and the graduation of the edge of the circle with more strongly cut divisions than those originally engraved on the face of the circle, the instrument remains and is figured in its original form. Pistor and Martins (Berlin) have also made excellent instruments of the above type. There is a celebrated micrometer of their make, with which, in the hands of Brunnow at Dunsink (Dublin), some of the most perfect and refined investigations ever made in practical astronomy have been executed.

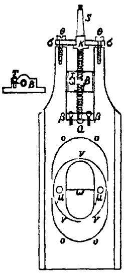


Fig 10

Dunsink micrometer.

In this micrometer the screw *s* is mounted on its own slide and has a divided head precisely like the screw S (fig 9). The plate *pp* is elongated towards *s*, and the corresponding bush B is attached to this elongation. The screw *s'* is shifted to another part of the eye piece slide, so that it does not interfere with the increased diameter of the screw *s*. Fraunhofer's micrometer in this form belongs to type A but is quoted under type B for convenience of description.

It is not necessary to give a figure representing type C. Such micrometers have been generally constructed on Troughton's type (figs 1, 2, 3) with the omission of one of the screws, and with one or more of the modifications described in detail under type A. Some have also been made similar otherwise to the Fraunhofer construction, by omitting the screw *s* with its corresponding slide and attaching the fixed wire to a circular plate in *pp*.

Clark's filar micrometer.

Good instruments have been made on type C by Clark (Cambridge, Massachusetts), by Steinheil (Munich), and by the great French artists Secretan, Froment, Brunner, Eichens, and good work has been done with them. But it is necessary that the errors of the screw should be very carefully determined since, in type C, such errors cannot be eliminated by employing different parts of the screw to measure the same angle. There is a noteworthy description of micrometer that forms a link between types C and D, of which the most famous example (by Clark) is attached to the great Washington telescope. It is essentially a micrometer of type C, with a slide (or fork) and a screw of the English form of construction. But the instrument is provided with a screw as at *s* (fig 9) which, instead of changing the position of the fixed wire, moves the whole micrometer box in the direction of the axis of the measuring screw. Thus the fixed wire can be set exactly on one star by the screw *s* while the other star is immediately afterwards bisected by the movable wire, and that without disturbing the reading for coincidence of the wires. No one, unless he has previously worked without such an arrangement, can fully appreciate the advantage of being able to bring up a star to bisection by the fixed wire by moving the micrometer box with a delicate screw motion, instead of having to change the direction of the axis of a huge telescope for the same purpose. When it is further remembered that the earlier telescopes were not provided with the modern slow motions in right ascension and that the Struves, in their gigantic labours among the double stars, used to complete their bisections of the stars by the delicate application of the finger on the side of the tube, one is puzzled whether most to wonder at the poor adaptation of the instruments or the marvellous patience and skill which, with such means, led to such results. It should be added that Dawes practically adopted a modification of Clark's micrometer by using a slipping piece and holding one of the heads of his micrometer (*Mem. R. A. S.*, vol. xxxv. p. 139). His slipping piece gave motion to the micrometer by two slides, one in right ascension the other in declination, so that "either of the webs can be placed upon either of the components of a double star with ease and certainty."

All micrometers used, in conjunction with a microscope, for reading the divisions of transit circles, heliometer scales, &c., are of the type C. The reading micrometer is shown in fig 11. C is the objective, D the micrometer box, E the graduated head of the screw, G the milled head by which the screw is turned, A an eye-piece sliding in a tube H (see fig 12) the slide,

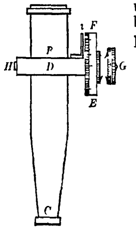


Fig 11.

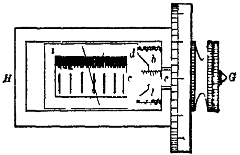


Fig 12

and *b*, *b* the spiral springs. The focal length of the objective and the distance between the optical centre of the lens and the webs are so arranged that images of the divisions are formed in the plane of the webs, and the pitch of the screw is such that one division of the scale corresponds with some whole number of revolutions of the screw.

There is what is technically called a "comb" inserted in the micrometer box at *d* (fig 12),—its upper surface being nearly in the plane of the wires. This comb does not move with reference to the box, and serves to indicate the whole revolution of which a fraction is read on the head. In fig 12 a division is represented bisected by cross webs, and five revolutions of the screw correspond with one division of the scale. In all modern reading micrometers the cross webs of fig 12 are replaced by parallel webs embracing the division

---

[1] When it is remembered that the measurements of the Struves, Dembowski, Secchi, the Bonds, Maclear, and of most modern Continental astronomers have been made with Fraunhofer or Merz micrometers, it is not too much to say that fig 9 represents the instrument with which three fourths of the astronomical measurements of the last fifty years have been made.

[2] The late Professor Watson used to say, quaintly and with truth, "After all, the best part of the micrometer is the man at the small end."

(fig 13) The means for changing the length of the tube and the distance of C from the scale are omitted in the figure These appliances are required if the "run" has to be accurately adjusted By "run" is meant the difference between the intended whole number of screw revolutions and the actual measure of the space between two adjacent divisions of the scale in turns of the screw divided by the number of intended revolutions In delicate researches two divisions of the scale should always be read, not merely for increased accuracy but to obtain the corrections for run from the observations themselves

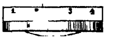


Fig 13

Repsold reading

Fig 14 represents an important type of reading micrometer by the Repsolds Here the web frame is mounted on the screw itself The limiting plane of motion is at *p*, where the end of the micrometer screw bears upon the hardened, flattened end of the screw *s*, and is kept in bearing against this plane by the spiral spring *q* Rotation

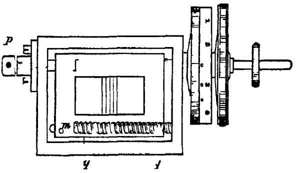


Fig 14

of the wire frame is prevented by the small stud ... which passes through the web frame and projects slightly on both sides of it, just barely touching the inner surface of the top and bottom of the

Micrometer errors

The comparative merits of the various micrometers [illegible]
by Lord Lindsay and Mr Gill (*Dunecht Publications*, vol ii pp 53 55 1877). If the screw of the Repsold micrometer is bent, so that for example, the end of the frame next the screw head is raised and that next the end *p* lowered, a twist will be given to the web frame and the centre of the wire will be moved nearer to the micrometer head than it should be while the reverse effect will follow when the head has been turned through 180° The effect of a similar error on the other micrometers described would be of a much less amount They are, however liable to errors of another character If as in Troughton's original micrometer the shoulder is square, the hole in the end of the box may be left sufficiently wide to allow for a small error in the parallelism of the screw matrix with the motion of the slide but the smallest bend in the screw causes the shoulder no longer to bear flat, but to ride on its edge, thus introducing an extremely uncertain form of error If the shoulder is spherical fitting into a hollow cone on the end of the box, as in the micrometers of Simms, Cooke and Grubb, an almost inconceivable accuracy of construction is implied in drilling the matrix of the screw in the slide so that its axis and that of the cone shall be in the same straight line and both parallel to the motion of a point in the slide Any departure from perfect accuracy in this respect has the effect of bringing different portions of the spherical shoulder to bear on different parts of the cone for different revolutions and introduces errors of a character by no means easy to deal with In addition to these objections there always is the greater objection of employing as a delicate contact measuring surface one that is exposed where oil is used Dust and oil will arrange themselves in layers of variable and uncertain thickness and defeat all attempts to secure absolutely consistent results In Repsold's micrometer the *point d'appui* is a small hardened and polished bearing requiring little lubrication, and perfectly protected from dust, the errors of the screw (some of them exaggerated certainly) are faithfully reproduced, and consequently determinable, and beyond this the work to be done by the screw is reduced to a minimum —no slide friction having to be overcome If we are to regard as the most perfect instrument "not that which has absolutely the smallest errors, but that which reproduces its errors with the most perfect consistency" undoubtedly Repsold's form of micrometer is best

In order to avoid the exaggeration of the screw errors produced by the non symmetrical position of the screw in Repsold's micrometer, Stone, in December 1879 exhibited at the Royal Astronomical Society and described *Monthly Notices* p 270), a modification of Repsold's instrument But, both in his statement of the comparative merits of the Troughton and Repsold micrometers and in the new form which he figures, Stone overlooks a strong point in the Repsold form, and in that proposed by Lord Lindsay and Gill three years previously,[1]—namely, the avoidance of all friction of the slide, and the elimination of all error or strain that may occur from a want of parallelism in the axis of the matrix and the motion of the slide

Lindsay Gill micrometer

The Lindsay Gill micrometer will be better understood from the following description In fig 15 Ss is the micrometer screw, its cylindrical axis is nicely ground to fit a hole in the side of the box [illegible] the same axis, but ground to a somewhat smaller cylinder, fits neatly but smoothly a hole in the web frame A screw, cut on the same axis, is tapped into the web frame at *s*, and the axis terminates in a pivot which fits a hole in a brass plate *cc* The end of the pivot—hardened and slightly rounded—rests on a flat agate[3] bearing *a*, which is imbedded in the plate B, and securely held *in situ* by pressure of the plate *cc* The plate B is firmly attached to the bottom of the box *q*, *q* are spiral springs mounted on pins Both springs and pin pass freely through the web frame at *p*, *p*, and the pins (but not the springs) pass freely through the frame at *n*, *n*[4] The parallel webs for observing the division (fig 13) are mounted on the forked end of the frame at *uu*

The web frame is narrower and thinner than the breadth and height of the interior of the box, and is only prevented from rotating by the delicate touch of the projecting ends of the pin *m* on the inner surfaces of the top and bottom of the box It appears that a frame so mounted fulfils all theoretical conditions of accuracy It is perfectly free to follow the motion of the screw and accurately to reproduce its errors notwithstanding any reasonable faults of workmanship, and no permissible shake or fouling of the bearing at *a* can produce sensible error in the distance between the bearing surface of the agate plane and the spider webs. The motion is produced with the minimum of friction, and the "feel" of the screw is therefore as delicate and perfect as it is possible to make it

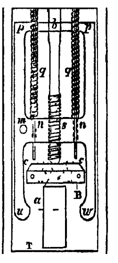


Fig 15

Repsold's micrometer

The micrometer of type D shown in fig 16 has recently been made by the Repsolds for the Cape Observatory As this instrument combines all their most recent modifications, we describe it in detail Fig 17 represents the same micrometer with the upper side of the box removed The letters in the description refer to both figures

S is the head of the micrometer screw, *s* that of the screw by which the micrometer box is moved relative to the plate *f* (fig 16), *s* that of the screw which moves the eye piece slide K is the clamp in position angle, P the slow motion screw in position angle, *pp* is the position circle, R, R its two readers The latter are in fact little microscopes carrying a vernier etched on glass in lieu of a filar micrometer These verniers can be read to 1 and estimated to 0 2 D is the drum head which gives the fraction of a revolution, *d* that which gives the whole number of revolutions, I is the index or pointer at which both drums are read This index is shown in fig 17, but only its mode of attachment (Y, fig 17) in fig 16 The teeth of the pinion *z*, fig 17, are cut on the axis of the micrometer screw The drum *d* and its attached tooth wheel are ground to turn smoothly on the axis of the screw The pinion *z* and the toothed wheel *d* are connected by an intermediate wheel and pinion Y, the numbers of teeth in the wheels and pinions are so proportioned that twenty four revolutions of the micrometer screw produce one revolution of the drum and wheel *d* (This is the description of Repsold's counter referred to under type A) The divisions of both drums are conveniently read, simultaneously, by

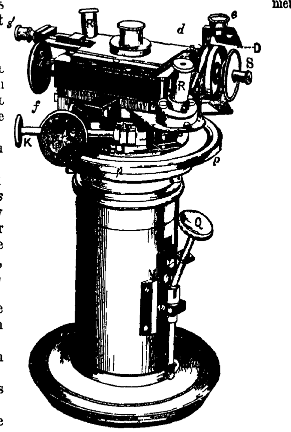


Fig 16

---

[1] *Dunecht Publications*, vol ii footnote p 55 Dunecht 1877

[2] There would be some advantage in allowing the screw's axis to pass with a little shake through the hole in the end of the box at *a* and then extending the length of the larger cylinder transfer the bearing from *a* to a well fitting hole in a piece fixed like B to the bottom of the box This form would also give some facilities of construction and all the oiled surfaces would be perfectly protected

[3] Sapphire is better, the agate bearing of such a screw has been found very sensibly worn

[4] If it is desired to prevent possible contact of these pins with the frame the ends of the pins may be made to enter guiding holes in *cc*

the lens e, at night the lamp which illuminates the webs and the position circle also illuminates the drum heads (see on illumination below). $aaaa$ is the web frame (fig. 17), $\beta\gamma$ is a single rod consisting of two cylinders accurately fitting in the ends of the micrometer box, the larger cylinder being at β. There is a hole in the web frame which smoothly fits the larger cylinder at β, and another which similarly fits the smaller cylinder at γ'. A spiral spring, coiled round the cylinder γ, resting one end on the shoulder formed by the difference of the diameters of the cylinders β and γ and the other on the inside of the web frame, presses the latter continuously towards γ. Contact of the web frame of the micrometer with the side of the box at γ would therefore take place were it not for the micrometer screw. This screw fits neatly in the end of the box at ϵ, passes loosely through the web frame at ϵ, is tapped into the frame at ζ, and its end rests on a flat hardened surface at ζ. Rotation of the web frame about $\beta\gamma$ is prevented by the heads of the screws at m, the head of the screw on the lower side of the frame reposes on the plane $\nu\nu$, that on the upper side (fig. 17) touches lightly on the inner surface of the lid of the box. Such rotation can obviously be controlled within limits that need not be further considered. But freedom of rotation in the plane of the paper (fig. 17) is only prevented by good fitting of the holes β, γ', and, since the weight of the slide is on one side of the screw, misfit here will have the effect of changing the reading for coincidence of the movable with the fixed web in reverse positions of the micrometer. With the Cape micrometer a systematic difference has been found in the coincidence point for head above and head below amounting to 0.14. This corresponds, in the Cape instrument, with an excess of the diameters of the holes over those of the cylinders of about $\frac{1}{15000}$th of an inch,—a quantity so small as to imply good workmanship, though it involves a systematic error which is very much larger than the probable error of a single determination of the coincidence point. The obvious remedy is to make all measures on opposite sides of the fixed web before reversing in position angle,—a precaution, however, which no careful observer would neglect. In measuring differences of declination, where the stars are brought up by the diurnal motion, this precaution cannot be adopted, because it is necessary always to bisect the preceding star with the fixed web. But in $\Delta\delta$ measures index error can always be eliminated by bisecting both stars with the same web (or different webs of known interval fixed on the same frame), and not employing the fixed web at all. Had the spring q been placed as in fig. 14 and the cylinders β and γ been made to bear like the pivots of a transit on segmental bearings in the frame at β and γ, it is probable that the difference in coincidence points would not have existed. Such a modification appears advisable, unless this construction, by leaving the end m less free, should make the "feel" of the screw less sweet and perfect. The discordance in zero when known to exist is really of no consequence, because the observations can be so arranged as to eliminate it.

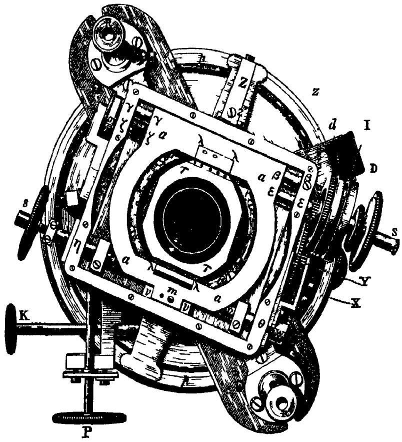


Fig 17

The box is mounted on a strong hollow steel cylinder CC (fig. 17) by holes η, θ in the ends of the box, which fit the cylinder closely and smoothly. The cylinder is rigidly fixed in the studs C, C and these are attached to the foundation plate f. The cylinder contains towards η a sliding rod, and towards θ a compressed spiral spring. There is thus a thrust outwards of the spring upon the hollow cap W (attached outside the box), and a thrust of the rod upon the end of the screw s. The position of the box relative to the plate f, in the direction of measurement, depends therefore on the distance between the end of the screw s and the fixed stud C. A screwing in of s thus causes the box to move to the left, and *vice versa*. Rotation of the box round CC is prevented by downward pressure of the spring Z on a projection attached to the side of the box. The amount of this pressure is regulated by the screw z.

The short screw whose divided milled head is σ shifts the zero of the micrometer by pushing, without turning, the short sliding rod whose flat end forms the *point d'appui* of the micrometer screw at ζ. The pitch of the screw σ is the same as that of the measuring screw (50 threads to the inch), and its motion can be limited by a stop to half a revolution.

The five fixed webs are attached to the table $\tau\tau$ which is secured to the bottom of the box by the screws ρ. The three movable webs are attached to the projections $\lambda\lambda$ on the frame aa. The plane surfaces $\tau\tau$ and $\lambda\lambda$ are composed of a bronze of very close texture, which appears capable of receiving a finish having almost the truth and polish of an optical surface. It seems also to take a very clean V cut, as the webs can be laid in their furrows with an astonishing ease and precision. These furrows have apparently been cut *in situ* with a very accurate engine, for not the slightest departure from parallelism can be detected in any of the movable webs relative to the fixed webs. Extraordinary care has evidently been bestowed in adjusting the parallelism and distance of the planes τ and λ, so that the movable wires shall almost, but not quite, touch the surface τ. The varnish to fix the webs is applied, not on the surface τ as is usual, but on a bevel for the purpose,[1] the position of the webs depending on their tension to keep them in their furrows. The result is that no trace of "fiddling" exists, and the movable and fixed webs come sharply together in focus with the highest powers. Under such powers the webs can be brought into apparent contact with such precision and delicacy that the uncertainty of measurement seems to lie as much in the estimation of the fraction of the division of the head as in the accuracy of the contact. It is a convenient feature in Repsold's micrometer that the webs are very near the inner surface of the top of the box, so that the eye is not brought inconveniently close to the plate when high powers are used.

Clark's micrometer for large angles.

Micrometers of the type F have been invented by Alvan Clark and Grubb. Clark's micrometer was exhibited at the June meeting of the Royal Astronomical Society in 1859 (*Monthly Notices R. A. S.*, vol. xix.). It is capable of measuring angles up to about one degree. It is "furnished with two eye-pieces composed of small single lenses mounted in separate frames which slide in a groove and can be separated to the required distance. A frame carrying two parallel spider lines, each mounted separately with its own micrometer screw, slides in a dovetailed groove in front of the eye-pieces, and by a free motion in this frame each web can be brought opposite its own eye-lens. In using this micrometer the first step is to set the position vernier to the approximate position of the objects to be measured. Then the eye-lenses are separated till each is opposite its own object. The frame containing the webs and their micrometer screws is then slid into its place, and the webs, having been separated nearly to their proper distance by their free motion in the frame, are placed precisely on the objects by their fine screws, the observer's eye being carried rapidly from one eye-lens to the other a few times, till he is satisfied of the bisection of each of the objects by its own web. The frame is then removed for reading off the measure by means of an achromatic microscope on the stage of which it is placed." The advantages which Clark claims are these:—

"1. Distances can be observed with great accuracy up to about one degree, and the angles of position also.

"2. The webs, being in the same plane, are perfectly free from parallax, and are both equally distinct, however high the magnifying power may be.

"3. The webs are also free from distortion and from colour.

"4. A different magnifying power may be used on each of the objects,—which may be advantageous in comparing a faint comet with a star."

It appears to us that the method of removing a slide in order to measure the interval between the webs is liable to objection, not only because of the risk to the webs, but because the taking of measurements of such a different character with a different instrument is inconvenient and troublesome. It is true that the intervals between the webs could be measured by an assistant, and two or more different slides be employed to save time, but astronomers will probably generally prefer the method introduced by Grubb described below. It is understood that Clark has since improved this instrument by an ingenious arrangement of prisms, which permits both webs, even though separated one degree in a large telescope, to be seen in the same eye-piece. The arrangement is not described, and is said to be, as yet, somewhat troublesome to arrange previous to measurement, though when arranged it gives very good results.

Grubb (*Scientific Proceedings of Royal Dublin Society*) thus describes

---

[1] The marks of varnish so applied will be seen in fig. 17.

Grubb's duplex micrometer

what he calls his "duplex micrometer," shown in perspective in fig. 18:—"A plate of glass about [illegible] inches square is ruled with twenty-one lines in one direction $\frac{1}{10}$th inch apart, and two lines in the other direction 2 inches apart. The extreme lines of the set therefore form a perfect square of 2 inches. These lines are ruled with exceeding accuracy and care, but provision is left for ascertaining any errors that may exist either as to distance or want of perfect squareness. Along one side of the square the micrometer ordinary [illegible] actuated by a screw of one hundred threads to the inch. This micrometer frame carries eleven lines corresponding exactly to each alternate line in the glass reticule so that when the first spider line is made coincident with the first diamond line on the glass the last spider line will be coincident with the last line on the glass, and each of the spider lines will be coincident with all the odd numbers of diamond lines 1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21. Over this glass plate is placed a [illegible] in which two eye-pieces are mounted, [illegible] at right angles to the other,—so that [illegible] journey backwards and forwards on the horizontal [illegible] various circumstances.

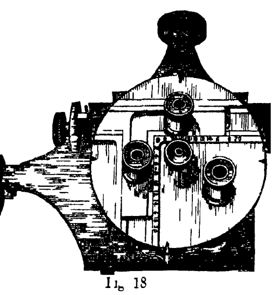


Fig. 18

"*How to Use the Instrument.*—1. The two stars are brought on the horizontal line, and the distance measured from centre to centre along that line. This distance is measured by counting the number of spaces on the glass, adding the residue as measured by the micrometer screw. Thus the screw is never used for larger measures than $\frac{1}{10}$th inch, and the [illegible] errors of screw and temperature errors are much reduced. In bisecting one star is brought into the field of one eye-piece and a bisection is made with one of the diamond lines by moving the micrometer by one or other of its slipping piece screws. Then the other eye-piece is moved till the second star is seen, and a bisection is made with the nearest spider line by moving the micrometer head. Then the eye can be moved back to the first eye-piece and the bisection checked, and again back to the other eye-piece. When it is seen that both are satisfactory the measure can be read off. 2. The micrometer is turned round till the horizontal line [illegible] is parallel to the path of apparent motion of the star. This is easily found by stopping the clock and allowing the star to run along the horizontal wire. Now the other star will be found to cross the vertical line somewhere, while the first star is on the horizontal line. This second star is then bisected on the vertical line, while the first star is bisected by one of the spider lines, thus the difference in right ascension is found. We then have two sides of a right-angled triangle, and of course all the elements are known.

"3. *To Ascertain the Errors of any of the Distances of the Lines.*—Of course the usual plan of taking transits can be adopted, and to ascertain if the lines are [illegible] angles a special additional eye-piece is provided so that transits can be taken across each diagonal of the square."

[illegible] instrument has great advantage over Clark's in ease of adjustment and use, and has done good work at the University Observatory, Oxford (*M. N. R. A. S.*, vol. xlvii. pp. 5 12). Professor Turner [illegible] too much when he estimates its work as equal in accuracy with that of the heliometer—at least the published results do not confirm such a view. But it is a very valuable instrument for measuring objects too faint for the limited aperture of most heliometers, and which at the same time are farther apart than the field of view of ordinary eye-pieces.

The accuracy of the duplex micrometer would be very greatly increased if Clark's idea (already mentioned) of viewing the widely separated webs in a single eye-piece of high power could be reduced to a convenient practical form.

Method of Webbing the Filar Micrometer.

The webbing of a micrometer is a process that should be familiar to all practical astronomers. English opticians usually proceed as follows. A spider (the variety is marked by a cross on the back, and is found in English gardens about decayed wood) is caught, and placed on a wire fork. The insect immediately attaches a web to the wire and begins to lower itself by a web to the ground. This web is wound up on the fork till ten or twelve turns, separated by a convenient space, have been secured. A brush with [illegible] then passed along the prongs, the webs are thus securely fixed to the fork. The parallel prongs of the fork must be sufficiently far apart to allow the web frame of the micrometer to pass between them. The frame to be webbed is placed on a flat dull black surface between the prongs of the fork, the latter being carefully arranged so that one of the webs lies nearly in the furrow ruled in the frame for its reception. As the web frame is generally thicker than the fork, the web will now be stretched across the former, with a certain amount of tension, and is brought into the furrow with a finely pointed piece of soft wood. If the surface of the frame is well polished, and the furrows sharply cut, without 'burr,' the web should leap sharply and decidedly into its place. Each end of the web is then secured by a drop of shellac varnish, which should be allowed to harden thoroughly before the frame is touched. The webs can be very readily so handled against a black background, with the aid of a hand lens of 2 or 3 inches focus. In experienced hands this method gives good results, but the following, which is generally followed on the Continent, is preferable.

A web, about 2 inches longer than the width of the frame, is unwound from a cocoon,[1] and small pieces of lead are attached to its extremities by beeswax. One end of the web, with its attached lead, is laid on a piece of cork floating in a tumbler of water; the other end is allowed to hang down in the water, where it becomes thoroughly saturated and untwisted. It is then laid across the fork, and dropped into its furrows in the manner above described, the little lead weights exerting a definite tension. Varnish[2] is immediately applied to secure the webs, and the frame is not touched till it is dry.

The bevel edge of the web frame introduced by Repsold (type D) offers great facilities for accurate webbing, and should be employed in all future micrometers.

Illumination of Micrometers.

When micrometer observations are made by night it is necessary to have some mode of rendering the webs visible—either by rays of light at right angles to the axis illuminating the webs, or by rays nearly coincident with the axis of the telescope. In the former case we get bright webs in a dark field, in the latter dark webs on a bright field.

In the older telescopes bright web illumination is produced by small lamps with nozzles that enter the tubes L L (fig. 9). The illumination is regulated in colour and intensity by wedges of coloured or darkened glass passing through slides in the nozzles. But it is inconvenient to have lamps so near the observer's eye, and it is at least very difficult to obtain a perfectly dark field when the wires are illuminated in this way.

The Clarks, in their micrometer of the great Washington telescope have made the end of box I (fig. 15) transparent, and light is thrown on the webs from a lamp held by an assistant. Holden has very recently applied a lamp ingeniously hung so as to preserve its verticality and the constant direction of its light in a similar way, adding a plain silvered mirror inside the box and opposite the lamp, so as to illuminate the webs symmetrically. In the Clarks' and Holden's methods it is only the webs at right angles to the screw that are illuminated.

For illumination of the field, in very old telescopes, light was thrown on a small ivory reflector fixed outside the object glass in the axis of the telescope by an arm fitting on the cell of the lens. This involved the aid of an assistant to direct lamplight on the ivory reflector, or the very frequent change of a lamp support. Afterwards the light from an attached lamp was introduced through a hole in the telescope tube and thrown upon an elliptical plane (generally dull gilt) having its centre part cut away sufficiently to avoid interruption of the cone of rays from the object glass. Many ingenious modes of suspending the lamp have been invented for the purpose of securing a constant direction of its light coupled with verticality of the lamp. One of the best of these, due to Cooke, is shown in fig. 19. L is the lamp, P a prism to reflect

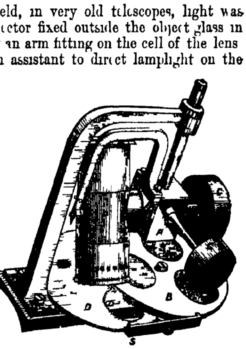


Fig. 19

---

[1] It is asserted that webs from cocoons are more elastic, better shaped, and more durable than those obtained during an effort of the insect to escape. The best webs we have seen were from a cocoon obtained in Holland, but we have been unable to ascertain the name of the variety of spider.

[2] Argelander used to apply two drops of varnish at each end of his webs. He first fixed each extremity by a drop of shellac varnish, and after that had dried he applied a drop of copal varnish nearer the centre of the frame; the latter took a long time to harden, but gave ultimately a much stronger attachment.

its light into the tube, D a disk to regulate the quantity of light, B a disk with glasses to regulate the colour of the light, S a spring to clamp the disks, C the counterpoise of the lamp, G a poise to preserve the horizontality of the axis CL But astronomers owe to the genius of Grubb the introduction of a more efficient and convenient system, viz, the performance of all necessary illumination of an astronomical telescope by a single lamp, and the perfect control of the illumination of the field or webs, and the regulation of these as to intensity or colour by simple motions from the eye end It is impossible to speak too highly of Grubb's efforts in this direction, he has broken the ground in this department of astronomical engineering, and rendered the working of so huge an instrument as the Vienna telescope of 27 inches aperture not only convenient, but easier for a single observer than that of a very small telescope of the older constructions

But in the illumination of the field wires and scales of a micrometer Grubb's original method has recently been surpassed by one which is due to the Repsolds We shall therefore describe the latter

Fig 20 represents the eye end of a telescope The reader will recognize the micrometer (figs 16 and 17) previously described L is a paraffin lamp fitting by a bayonet joint into a copper cover c This effectually defends its glass chimney against accident, and protects the lamp from wind The simple means by which this lamp is made to preserve its verticality in all positions of the telescope is evident from the figure By this lamp alone the bright wire or bright field illumination is given at pleasure, and with any desired intensity simply by movement of the small pin p

The position circle and the head of the micrometer are also illuminated, as well as the declination circle, by the same lamp AB is a cylindrical box, ending in a truncated cone towards A It is shown, mid section, in a plane passing through the telescope axis, in fig 21, where all details unnecessary to the explanation of the illumination are omitted and proportion of parts is sacrificed to clearness P is a prism (fig 21) that rotates with the lamp and reflects its light into AB The flame of the lamp is in the focus of the lens ll, so that the rays become parallel after passing through it There is a sliding motion to perfect this adjustment There is a well polished flat annular reflector of speculum metal rr (fig 21), which reflects light upon the double mirror M (fig 20) whence it is diverted to the two opposite points on the declination circle that are read by micrometer microscopes from the eye end (the latter are omitted for sake of clearness)

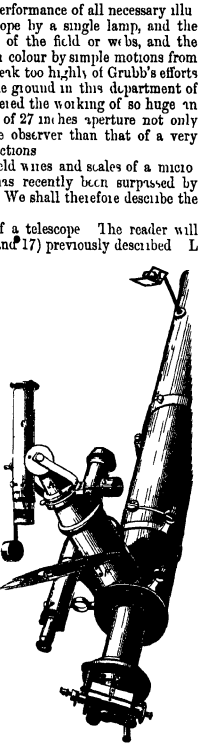


Fig 20

The little handle at p and the dotted lines pz represent an iris diaphragm, very ingeniously constructed, mounted on a plate of transparent glass There is a flat ring of brass carrying four pins, which is turned by the handle p, in a plane at right angles to Pn These pins work in spiral slots cut in four slides Thus rotation of the ring causes the four slides to approach or recede from a centre When the handle p is in the middle of its range, the slides together form a disk as large as the hole in the diaphragm dd, and thus prevent all light from entering the telescope tube When p′ is pushed to one side of its range the slides move outwards leaving a square opening in the centre so that the light falls on the prism n, whence it is diverted to a silvered reflector cemented on the middle of the inner surface of the object glass, and is then reflected back along the axis of the telescope to illuminate the field at ω When p is pushed to the other side of its range the slides approach and overlap at the centre, excluding light from n and allowing it to fall upon the reflector s instead From s the light is thrown upon the webs ω, ω by reflexion from a white papier maché surface laid on the inside of a thin hollow brass truncated cone xx The edge of this cone forms the circle seen within rr in fig 17 All stray light is prevented by the light guard tube mm, which is attached to and moves with the rotating part of the micrometer The result is to produce a symmetrical illumination of the whole system of webs in a perfectly dark field It is also obvious that by placing p at an intermediate position between the centre and the extremes of its range any desired modification of bright wire or bright field illumination can be obtained at pleasure

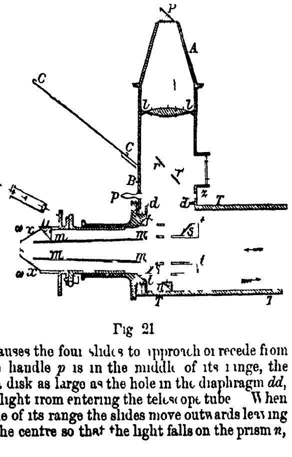


Fig 21

The light falling on the papier maché hollow cone is intercepted at three points by prisms, one of which μ is shown in section These prisms are inserted in the cylinder which carries the foundation plate of the micrometer box and rotate with it Two of them divert light upon the reflectors (seen from different points of view in figs 16, 17, 20) The third prism after two reflexions (figs 16 20) illuminates the micrometer head The whole arrangement is in the highest degree elegant, and we have found it most simple and convenient in practice The screen C (figs 20 and 21)—made of thin copper and attached to AB—effectually protects the observer's eye from stray light from the lamp

It has been found essential, in bright field illumination, when the highest accuracy is desired, to have the illuminating rays parallel with the telescope axis

In the best telescopes of the future some plan like that of Repsolds above described will doubtless be adopted It is probable also that with the introduction of condensers in conjunction with the incandescent carbon light in vacuum, electricity will ultimately supersede the oil or paraffin lamp in illuminating astronomical instruments A small Swan lamp can be placed anywhere, is unaffected by wind, and gives off comparatively little heat These are most valuable qualities for the purpose in question

The astronomer royal (Mr Christie) has recently used luminous paint to render the measuring pointer of the Greenwich spectroscope visible at night This paint after exposure during the day to sunlight, shines at night with a dull phosphorescence sufficient to make the micrometer pointer, to which it is applied, faintly visible, and, it is stated, with very satisfactory results

On the use of the filar micrometer consult Struve *Mensuræ Micrometricæ* St Petersburg 1837 Brunnow *Practical and Spherical Astronomy* Chauvenet *Practical and Spherical Astronomy* Brunnow *Astronomical Observations and Researches made at Dunsink* Dublin 1870 1873 1879 Ball *ibid* Kaiser *Leiden Observations* and the papers of Dembowski in the *Astronomische Nachrichten*

Double Image Micrometers

The discovery of the method of making measures by double images is stated to have been first suggested by Roemer about 1678 R But no such suggestion occurs in the *Basis Astronomiæ* of Horrebow (Copenhagen, 1735), which contains the only works of Roemer that remain to us It would appear that to Savary is due the first invention of a micrometer for measurement by double image His heliometer (described in a paper communicated to the Royal Society in 1743 and printed, along with a letter from Short, in *Phil Trans*, 1753, p 165) was constructed by cutting from a complete lens *abcd* the equal portions *aghc* and *acfe* (fig 22) The segments *gbh* and *efd* so formed were then attached to the end of a tube having an internal diameter represented by the dotted circle (fig 23) The width of each of the portions *aghc* and *acfe* cut away from the lens was made slightly greater than the focal length of lens × tangent of sun's greatest diameter Thus at the focus two images of the sun were formed nearly in contact as in fig 24 The small interval between the adjacent limbs was then measured with a wire micrometer

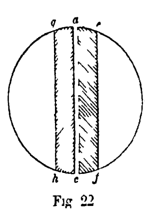


Fig 22

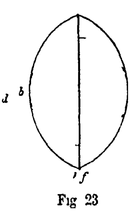


Fig 23

Savary also describes another form of heliometer on the same principle, in which the segments *aghc* and *acfe* a[illegible] l by cementing their edges *gh* and *ef* together (fig 25) and covering all except the portion indicated by the unshaded circle Savary expresses preference for this second plan, and makes the pertinent remark that in both these models "the rays of red light in the two solar images will be next to each other, which will render the sun's disk more easy to be observed than the violet ones This Savar he mentions "because the glasses in these two sorts are somewhat prismatical, but mostly those of the first model, which could therefore bear no great charge" (magnifying power).

A third model proposed by Savary consists of two complete lenses of equal focal length mounted in cylinders side by side and attached to a strong brass plate (fig. 26). Here in order to fulfil the purposes of the previous models the distance of the centres of the lenses from each other should only slightly exceed the tangent of sun's diameter × focal length of lenses. Savary dwells on the difficulty both of procuring lenses sufficiently equal in focus and of accurately adjusting and centring them.

Bouguer In the *Mem. Acad. de Paris* 1748 Bouguer describes an instrument which he calls a heliometer. Lalande in his *Astronomie* (vol. ii p. 639) mentions such a heliometer which had been in his possession from the year 1753, and of which he gives a representation on Plate XXVIII., fig. 180 of the same volume. Bouguer's heliometer was in fact similar to that of Savary's third model with the important difference that instead of both object glasses being fixed one of them is movable by a screw provided with a divided head. No auxiliary filar micrometer was required as in Savary's heliometer to measure the interval between the limbs of two adjacent images of the sun, it being only necessary to turn the screw with the divided head to change the distance between the object glasses till the two images of the sun are in contact as in fig. 27. The differences of the readings of the screw, when converted into arc afford the means of measuring the variations of the sun's apparent diameter.

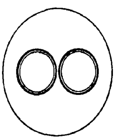


Fig. 26

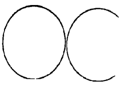


Fig. 27

Dollond On the 4th April 1754 Dollond communicated a paper to the Royal Society of London (*Phil. Trans.*, vol. xlviii p. 551) in which he shows that a micrometer can be much more easily constructed by dividing a single object glass through its axis than by the employment of two object glasses. He points out—(1) that a telescope with an object glass so divided still produces a single image of any object to which it may be directed provided that the optical centres of the segments are in coincidence (*i.e.* provided the segments retain the same relative positions to each other as before the glass was cut), (2) that if the segments are separated in any direction two images of the object viewed will be produced, (3) that the most convenient direction of separation for micrometric purposes is to slide these straight edges one along the other as the figure on the margin (fig. 28) represents them "for thus they may be moved without suffering any false light to come in between them, and by this way of removing them the distance between their centres may be very conveniently measured viz by having a vernier's division fixed to the brass work that holds one segment, so as to slide along a scale on the plate to which the other part of the glass is fitted."

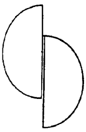


Fig. 28

Dollond then points out three different types in which a glass so divided and mounted may be used as a micrometer —

"1 It may be fixed at the end of a tube of a suitable length to its focal distance as an object glass—the other end of the tube having an eye glass fitted as usual in astronomical telescopes.

"2 It may be applied to the end of a tube much shorter than its focal distance by having another convex glass within the tube to shorten the focal distance of that which is cut in two.

"3 It may be applied to the open end of a reflecting telescope either of the Newtonian or the Cassegrain construction."

yet it is the first type that has survived the test of time and experience and which is in fact the modern heliometer.

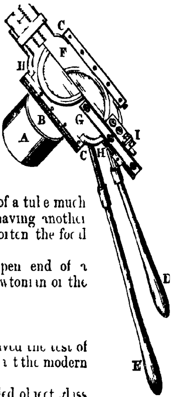


Fig. 29

Fig. 29 illustrates Dollond's divided object glass heliometer of the third type. A is the end of the reflecting telescope upon which the adapter B is fitted. B carries a wheel (not seen in the figure) formed of a ring racked at the outer edge, and fixed to the brass plate CC so that a pinion moved by the handle D may turn it into any position. Two plates F, G, with the attached semi lenses, move in slides fixed to the plate CC,—simultaneous motion, in contrary directions, being communicated to them by turning the handle E, which drives a concealed pinion that works in the two racks seen in the highest part of the figure. The amount of separation of the semi lenses is measured by a scale 5 inches long, subdivided to $\frac{1}{20}$th of an inch, and read by a vernier on the plate F to $\frac{1}{500}$th of an inch. In practical use this micrometer has never given satisfactory results (see Mosotti in the *Effemeride* of Milan for 1821). It must be remembered, however, that when Dollond gave preference to this type he had not invented the achromatic object glass, his preference was fully justified under these circumstances. So far as we know no heliometer with a divided achromatic object glass was ever made by the elder Dollond on the principle of his first type. His son, however, made what he called an object glass micrometer, which was a great improvement on the elder Dollond's second type.

In the older construction the brass mountings of the semi lenses obstructed the light entering the telescope in proportion to their separation and the images were so coloured as to prevent the use of any but very low powers. In the later construction the movable segments are formed from a negative achromatic lens of much larger aperture than the object glass of the telescope with which the micrometer is employed and, for convenience in mounting, the segments *gbh* and *cdf* (fig. 22) are removed. In the fine example of this instrument at the Royal Observatory, Cape of Good Hope, the movable lenses consist of segments of the shape *gach* and *eacf* (fig. 22) cut from a complete negative achromatic combination of $8\frac{1}{4}$ inches aperture and about 41 feet focal length composed of a double concave flint lens and a double convex crown. This is applied to an excellent achromatic telescope of $3\frac{1}{4}$ inches aperture and 42 inches focal length. The instrument is represented in fig. 30 the same letters indicate the analogous parts of fig. 29. The frame CC moved by teeth on its outer edge, carries one of the halves G of the lens and a similar frame with teeth carries the other half F. A scale $8\frac{1}{2}$ inches long is fastened like an edge bar to the frame of the segment G, and each inch is subdivided into twenty parts, which are read off by a vernier to $\frac{1}{1000}$th of an inch, and by estimation, this can easily be carried to $\frac{1}{2000}$th or $\frac{1}{3000}$th of an inch. The two movable frames are imbedded in a fixed plate HH, screwed to the adapter B, having a circular hole in its middle equal to the diameter of the object glass. The slide of the segment G is moved by turning the milled head to the right of A and the other segment F by means of a rack and pinion on the opposite side, the latter being turned from the eye end by a handle not seen in the figure. A screw is provided for clamping the slide of the segment G, as it is intended that only the segment F shall be moved in making the final bisection. There is an index attached to the slide of G reading on a rough scale engraved on the plate H which is obviously intended for setting the optical centre of the segment G approximately as far from the optical axis of the telescope on one side as the optical centre of the segment F will be on the other side during the intended measurement. This arrangement not only permits the measurement of angles twice as great as would be possible if one segment were fixed, but is also important in increasing the symmetry of the measures. The vernier is placed at one end of the scale when the optical centres of the segments are in coincidence and is provided with screws at I, which are intended for adjusting the zero of the scale. The younger Dollond has in this model retrograded, in some respects, from the admirable example of his father, who as shown in fig. 29, not only gave the lenses automatic opposite motion symmetrically with respect to the axis of the telescope, but seems also to have provided for entire elimination of index error by making it possible to observe all angles on opposite sides of zero—a precaution possible in the later form only when very small angles are measured. Rotation of the micrometer in position angle is provided for as in the earlier form, but the instrument is not furnished with a position circle.

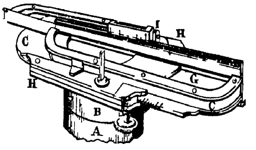


Fig. 30

Triesnecker's measurements With one of these instruments of somewhat smaller dimensions (telescope $2\frac{1}{2}$ inches aperture and $3\frac{1}{2}$ feet focus) Triesnecker made a series of measurements at the observatory of Vienna which has been recently reduced by Dr Schur of Strasburg (*Nova Acta der Ksl. Leop. Carol. Deutschen Akademie der Naturforscher* xlv No. 3). The angle between the stars ζ and *g* Ursæ maj. (708 55) was measured on four nights, the probable error of a measure on one night was ± 0 44. Jupiter was measured on eleven nights in the months of June and July 1794, from these measures Schur derives the values 35 39 and 37 94 for the polar and equatorial diameter respectively, at mean distance, corresponding with a compression 1/14 44. These agree satisfactorily with the corresponding values

35″ 21, 37″ 60, 1/15 69 afterwards obtained by Bessel (*Königsberger Beobachtungen*, xix 102) From a series of measures of the angle between Jupiter's satellites and the planet, made in June and July 1794 and in August and September 1795, Schur finds the mass of Jupiter = $\frac{1}{1048\ 55\pm1\ 45}$, a result which accords perfectly with the received value of the mass derived from modern researches The probable errors for the measures of one night are ±0 577, ±0 889, ±0′ 542, ±1 096, for Satellites I, II, III, and IV respectively It is probable that Triesnecker deduced the index error from his measures of the diameter of Jupiter, as, in 1794, the measures of diameter are made on the same nights with those of the measures of distance of the satellites, and it is possible that measures of diameter may have been made in 1795 but not published

Considering the accuracy of these measures (an accuracy far surpassing that of any contemporary observations), it is somewhat surprising that this form of micrometer was never systematically used in any sustained or important astronomical researches, although a number of instruments of the kind were made by Dollond Probably the last example of its employment is an observation of the transit of Mercury (November 4, 1868) by Mr Mann, at the Royal Observatory, Cape of Good Hope (*Monthly Notices R A S*, vol xxix p 197–209) The most important part, however, which this type of instrument seems to have played in the history of astronomy arises from the fact that one of them was in the possession of Bessel at Königsberg during the time when his new observatory there was being built In 1812 Bessel measured with it the angle between the components of the double star 61 Cygni and observed the great comet of 1811 He also observed the eclipse of the sun on May 4, 1818 In the discussion of these observations (*Königsberger Beobacht*, Abth 5 p iv) he found that the index error of the scale changed systematically in different position angles by quantities which were independent of the direction of gravity relative to the position angle under measurement, but which depended solely on the direction of the measured position angle relative to a fixed radius of the object glass Bessel attributed this to non homogeneity in the object glass, and determined with great care the necessary corrections But he was so delighted with the general performance of the instrument, with the sharpness of the images, and the possibilities which a kindred construction offered for the measurement of considerable angles with micrometric accuracy, that he resolved, when he should have the choice of a new telescope for the observatory, to secure some form of heliometer

observations

Nor is it difficult to imagine the probable course of reasoning which led Bessel to select the model of his new heliometer Why he might ask, should he not select the simple form of Dollond's first type? Given the achromatic object glass, why should not it be divided? This construction would give all the advantage of the younger Dollond's object glass micrometer and more than its sharpness of definition, without liability to the systematic errors which may be due to want of homogeneity of the object glass, for the lenses will not be turned with respect to each other, but, in measurement, will always have the same relation in position angle to the line joining the objects under observation It is true that the scale will require to be capable of being read with much greater accuracy than $\frac{1}{00}$th of an inch—for that, even in a telescope of 10 feet focus, would correspond with 2″ of arc But, after all this is no practical difficulty,—for screws can be used to separate the lenses, and, by these screws, as in a Gascoigne micrometer, the separation of the lenses can be measured, or we can have scales for this purpose, read by microscopes, like the Troughton[1] circles of Piazzi or Pond, or those of the Carey circle, with almost any required accuracy

Fraunhofer

Whether Bessel communicated such a course of reasoning to Fraunhofer, or whether that great artist arrived independently at like conclusions, we have been unable to ascertain with certainty The fact remains that before 1820[2] Fraunhofer had completed one or more of the five heliometers (3 inches aperture and 39 inches focus) which have since become historical instruments In 1824 the great Königsberg heliometer was commenced, and it was completed in 1829

To sum up briefly the history of the heliometer The first application of the divided object glass and the employment of double images in astronomical measures is due to Savary in 1743 To Bouguer in 1748 is due the true conception of measurement by double image without the auxiliary aid of a filar micrometer viz, by changing the distance between two object glasses of equal focus To Dollond in 1754 we owe the combination of Savary's idea of the divided object glass with Bouguer's method of measurement, and the construction of the first really practical heliometers To Fraunhofer, some time not long previous to 1820 is due so far as we can ascertain, the construction of the first heliometer with an achromatic divided object glass, *i e*, the first heliometer of the modern type

Double Image Micrometers with Divided Lenses

Various micrometers have been invented besides the heliometer for measuring by double image Ramsden's dioptric micrometer consists of a divided lens placed in the conjugate focus of the innermost lens of the erecting eye tube of a terrestrial telescope The inventor claimed that it would supersede the heliometer, but it has never done anything for astronomy Dollond claims the independent invention and first construction of a similar instrument (Pearson's *Practical Astronomy* vol ii p 182) Of these and kindred instruments only two types have proved of practical value Amici of Modena (*Mem Soc Ital*, xvii (1815) pp 344–359) describes a micrometer in which a negative lens is introduced between the eye piece and the object glass This lens is divided and mounted like a heliometer object glass, the separation of the lenses produces the required double image, and is measured by a screw Dawes has very successfully used this micrometer in conjunction with a filar micrometer, and finds that the precision of the measures is in this way greatly increased (*Monthly Notices*, vol xviii p 58, and *Mem R A S*, vol xxxv p 147)

In the improved form[3] of Airy's divided eye glass micrometer (*Mem R A S*, vol xv pp 199 209), the rays from the object glass pass successively through lenses as follows

Lens	Distance from next Lens	Focal Length
a An equiconvex lens	*p*	arbitrary $=p$
b	2	5
c Plano convex convex towards *b*	$1\frac{3}{4}$	1
d Plano convex convex towards *c*		1

The lens *b* is divided and one of the segments is moved by a micrometer screw The magnifying power is varied by changing the lens *a* for another in which *p* has a different value The magnifying power of the eye piece is that of a single lens of focus $=\frac{4}{5}p$

In 1850 Valz pointed out that the other optical conditions could be equally satisfied if the divided lens were made concave instead of convex with the advantage of giving a larger field of view (*Monthly Notices*, vol x p 160)

The last improvement on this instrument is mentioned in the *Report* of the R A S council, February 1865 It consists in the introduction by Simms of a fifth lens but no satisfactory description has ever appeared There is only one practical published[4] investigation of Airy's micrometer that is worthy of mention, viz, that of Kaiser (*Annalen der Sternwarte in Leiden*, iii pp 111–274) The reader is referred to that paper for an exhaustive history and discussion of the instrument[5] It is somewhat surprising that, after Kaiser's investigations, observers should continue, as many have done, to discuss their observations with this instrument as if the screw value were constant for all angles

Steinheil's ocular micrometer

Steinheil (*Journal Savant de Munich*, 28th February 1843) describes a "heliometre oculaire" which he made for the great Pulkowa refractor, the result of consultations between himself and the elder Struve It is essentially the same in principle as Amici's micrometer, except that the divided lens is an achromatic positive instead of a negative lens Struve (*Description de l Observatoire Central de Poulkova*, pp 196, 197) adds a few remarks to Steinheil's description, in which he states that the images have not all desirable precision,—a fault perhaps inevitable in all micrometers with divided lenses, and which is probably in this case aggravated by the fact that the rays falling upon the divided lens have considerable convergence He however successfully employed the instrument in measuring double stars, so close as 1″ or 2″, and using a power of 300 diameters, with results that agreed satisfactorily amongst themselves and with those obtained with the filar micrometer If Struve had employed a properly proportioned double circular diaphragm fixed symmetrically with the axis of the telescope in front of the divided lens and turning with the micrometer, it is probable that his report on the instrument would have been still more favourable This particular instrument has historical interest having led Struve to some of those criticisms of the Pulkowa heliometer which ultimately bore such valuable fruit (see below)

---

[1] The circles by Reichenbach, then almost exclusively used in Germany read by verniers only

[2] The diameter of Venus was measured with one of these heliometers [illegible] observatory of Breslau by Brandes in 1820 (*Berlin Jahrbuch* 1824, p 164)

[3] For description of the earliest form see *Cambridge Phil Trans* vol ii and *Greenwich Observations* 1840

[4] We understand that a very thorough investigation of Airy's double image micrometer used by Dr Copeland at Mauritius on Lord Lindsay's expedition has been made by him and will soon be published

[5] Dawes (*Monthly Notices* January 18[illegible] and *Mem R A S* vol xxxv p 1[illegible]0) has suggested and used a valuable improvement for producing round images instead of the elongated images which are otherwise inevitable when the rays pass through a divided lens of which the optical centres are not in coincidence viz the introduction of a diaphragm having two circular apertures touching each other in a point coinciding with the line of collimation of the telescope and the diameter of each aperture *exactly equal* to the semidiameter of the cone of rays at the distance of the diaphragm from the focal point of the object glass Practically the difficulty of making these diaphragms for the different powers of [illegible] a certain amount of light we see no reason why they [illegible] not readily be [illegible] slightly less Dawes found the best method for the purpose in question was to limit the aperture of the object glass by a diaphragm having a double circular aperture placing the line joining the centres of the circles approximately in the position angle under measurement Dawes successfully e[illegible] [illegible] has [illegible] metho[illegible] viz, by placing circular diaphragms c[illegible]

Ramsden (*Phil Trans* vol xix p 419) has suggested the division of the small speculum of a Cassegrain telescope and the production of double image by micrometric rotation of the semi specula in the plane passing through their axis Brewster (*Ency Brit* 8th ed vol xiv p 749) proposes a plan on a like principle, by dividing the plane mirror of a Newtonian telescope Again, in an ocular heliometer by Steinheil double image is similarly produced by a divided prism of total reflexion placed in parallel rays But practically these last three methods are failures In the last the field is full of false light and it is not possible to give sufficiently minute and steady separation to the images and there are of necessity a collimator two prisms of total reflexion, and a small telescope through which the rays must pass, consequently there is great loss of light

Micrometers Depending on Double Refraction

Rochon's micrometer

To the Abb Rochon (*Jour de Phys*, liii 1801 pp 169 198) is due the happy idea of applying the two images formed by double refraction to the construction of a micrometer He fell upon a most ingenious plan of doubling the amount of double refraction of a prism by using two prisms of rock crystal so cut out of the solid as to give each the same quantity of double refraction and yet to double the quantity in the effect produced The combination so formed is known as Rochon's prism Such a prism he placed between the object glass and eye piece of a telescope The separation of the images increases as the prism is approached to the object glass and diminishes as it is approached towards the eye piece

Arago (*Comptes Rendus* xxiv 1847 pp 400 402) found that in Rochon's micrometer when the prism was approached close to the eye piece for the measurement of very small angles the smallest imperfections in the crystal or its surfaces were inconveniently magnified He therefore selected for any particular measurement such a Rochon prism as when fixed between the eye and the eye piece (*i e* where a sunshade is usually placed) would combined with the normal eye piece employed bring the images about to be measured nearly in contact He then altered the magnifying power by sliding the field lens of the eye piece (which was fitted with a slipping tube for the purpose) along the eye tube, till the images were brought into contact By a scale attached to the sliding tube the magnifying power of the eye piece was deduced, and this combined with the angle of the prism employed gave the angle measured If p is the refracting angle of the prism and n the magnifying power of the eye piece then p/n will be the distance observed Arago made many measures of the diameters of the planets with such a micrometer

Dollond (*Phil Trans*, 1821, pp 101 103) describes a double image micrometer of his own invention in which a sphere of rock crystal is substituted for the eye lens of an ordinary eye piece In this instrument (figs 31, 32 a is the sphere placed in half holes on the axis bb so that when its principal axis is parallel to the axis of the telescope it gives only one image of the object In a direction perpendicular to that axis it must be so placed that when it is moved by rotation of the axis bb the separation of the images shall be parallel to that motion The angle of rotation is measured on the graduated circle C The angle between the objects measured is $= r \sin 2\theta$ where r is a constant to be determined for each magnifying power employed[1] and θ the angle through which the sphere has been turned from zero (*i e* from coincidence of its principal axis with that of the telescope) The maximum separation is consequently at 45° from zero The measures can be made on both sides of zero for eliminating index error There are considerable difficulties of construction but these have been successfully overcome by Dollond, and in the hands of Dawes (*Mem R A S*, xxxv p 144 *sq*) such instruments have done valuable service They are liable to the objection that their employment is limited to the measurement of very small angles, viz, 13 or 14 when the magnifying power is 100, and varying inversely as the power Yet the beautiful images which these micrometers give permit the measurement of very difficult objects as a check on measures with the parallel wire micrometer

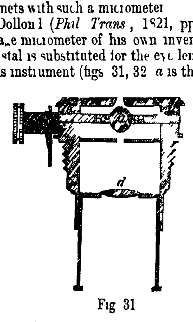


Fig 31

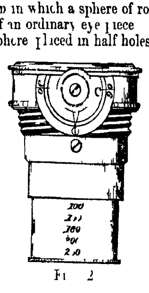


Fig 32

The Modern Heliometer

Konigsberg helio-

The Konigsberg heliometer is represented in fig 33 No part of the equatorial mounting is shown in the figure, as it resembles in every respect the usual Fraunhofer mounting An adapter h is fixed on a telescope tube, made of wood, in Fraunhofer's usual fashion To this adapter is attached a flat circular flange h The slides carrying the segments of the divided object glass are mounted on a plate which is fitted and ground to rotate smoothly on the flange h Rotation is communicated by a pinion turned by the handle c (concealed in the figure), which works in teeth cut on the edge of the flange h The counterpoise u balances the head about its axis of rotation The slides are moved by the screws a and b, the divided heads of which serve to measure the separation of the segments These screws are turned from the eye end by bevelled wheels and pinions, the latter connected with the handles a, b' The reading micrometers e, f also serve to measure, independently, the separation of the segments, by scales attached to the slides, such measurements can be employed as a check on those made by the screws The measurement of position angles is provided for by a graduated circle attached to the head There is also a position circle, attached at m to the eye end, provided with a slide to move the eye piece radially from the axis of the telescope, and with a micrometer to measure the distance of an object from that axis The ring which carries the supports of the handles a, b, c is capable of a certain amount of rotation on the tube The weight of the handles and their supports is balanced by the counterpoise z This ring is necessary in order to allow the rods to follow the micrometer heads when the position angle is changed Complete rotation of the head is obviously impossible because of the interference of the declination axis with the rods and therefore in some angles objects cannot be measured in two positions of the circle The object glass has an aperture of 6½ inches, and 102 inches focal length

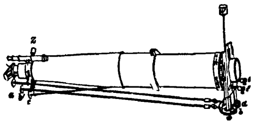


Fig 33

There are three methods in which this heliometer can be used

First Method —One of the segments is fixed in the axis of the telescope, and the eye piece is also placed in the axis Measures are made with the moving segment displaced alternately on opposite sides of the fixed segment

Second Method —One segment is fixed, and the measures are made as in the first method, excepting that the eye piece is placed symmetrically with respect to the images under measurement For this purpose the position angle of the eye piece micrometer is set to that of the head and the eye piece is displaced from the axis of the tube (in the direction of the movable segment) by an amount equal to half the angle under measurement

Third Method —The eye piece is fixed in the axis and the segments are symmetrically displaced from the axis each by an amount equal to half the angle measured

Of these methods Bessel generally employed the first because of its simplicity, notwithstanding that it involved a resetting of the right ascension and declination of the axis of the tube with each reversal of the segments The chief objections to the method are that, as one star is in the axis of the telescope and the other displaced from it, the images are not both in focus of the eye piece[2] and the rays from the two stars do not make the same angle with the optical axis of each segment Thus the two images under measurement are not defined with equal sharpness and symmetry The second method is free from the objection of non coincidence in focus of the images, but is more troublesome in practice from the necessity for frequent readjustment of the position of the eye piece The third method is the most symmetrical of all, both in observation and reduction but it was not employed by Bessel, on the ground that it involved the determination of the errors of two screws instead of one On the other hand it is not necessary to reset the telescope after each reversal of the segments[3]

---

[2] The distances of the optical centres of the segments from the eye piece are in this method as 1 : secant of the angle under measurement In Bessel's heliometer this would amount to a difference of $\frac{1}{1000}$th of an inch when an angle of 1° is measured For two degrees the difference would amount to nearly $\frac{1}{10}$th of an inch Bessel confined his measures to distances considerably less than 1

[3] In criticizing Bessel's choice of methods and considering the loss of time involved in each it must be remembered that Fraunhofer provided no means of

When Bessel ordered the Konigsberg heliometer, he was anxious to have the segments made to move in cylindrical slides, of which the radius should be equal to the focal length of the object glass. Fraunhofer, however, did not execute this wish, on the ground that the mechanical difficulties were too great.

Wichmann states (*Konigsb. Beobach.*, xxx. p. 4) that Bessel had indicated, by notes in his handbooks, the following points which should be kept in mind in the construction of future heliometers:—(1) The segments should move in cylindrical slides;[1] (2) the screw should be protected from dust;[2] (3) the zero of the position circle should not be so liable to change;[3] (4) the distance of the optical centres of the segments should not change in different position angles or otherwise;[4] (5) the points of the micrometer screws should rest on ivory plates;[5] (6) there should be an apparatus for changing the screen.[6]

The elder Struve, in describing the Pulkowa heliometer[7] made by Merz in 1839 on the model of Bessel's heliometer, submits the following suggestions for its improvement:[8]—(1) to give automatically to the two segments simultaneous equal and opposite movement,[9] and (2) to make the tube of brass instead of wood, to attach the heliometer head firmly to this tube, to place the eye piece permanently in the axis of the telescope, and to fix a strong cradle on the end of the declination axis, in which the tube, with the attached head and eye piece, could rotate on its axis.

Both suggestions are important. The first is originally the idea of Dollond (fig. 29), its advantages were overlooked by his son (description of fig. 30), and it seems to have been quite forgotten till resuggested by Struve. But the method is not available if the separation is to be measured by screws; it is found, in that case, that the direction of the final motion of turning of the screw must always be such as to produce motion of the segment against gravity, otherwise the "loss of time" is apt to be variable. Thus the simple connexion of the two screws by cog wheels to give them automatic opposite motion is not an available method unless the separation of the segments is independently measured by scales.

Struve's second suggestion has been adopted in nearly all succeeding heliometers. It permits complete rotation of the tube and measurement of all angles in reversed positions of the circle; the handles that move the slides can be brought down to the eye end, inside the tube, and consequently made to rotate with it; and the position circle may be placed at the end of the cradle next the eye end where it is convenient of access. Struve also points out that by attaching a fine scale to the focussing slide of the eye piece and knowing the coefficient of expansion of the brass tube, the means would be provided for determining the absolute change of the focal length of the object glass at any time by the simple process of focussing on a double star. This with a knowledge of the temperature of the screw or scale and its coefficient of expansion, would enable the change of screw value to be determined at any instant. Or, if we suppose the temperature of the instrument to be the same in all its parts, the changed scale value becomes simply a function of the reading of the focal scale.

Bonn heliometer.

It is probable that the Bonn heliometer was in course of construction before these suggestions of Struve were published or discussed, since its construction resembles that of the Konigsberg and Pulkowa instruments. Its dimensions are similar to those of the former instrument. Bessel, having been consulted by the celebrated statesman Sir Robert Peel, on behalf of the Radcliffe trustees, as to what instrument, added to the Radcliffe Observatory, would probably most promote the advancement of astronomy, strongly advised the selection of a heliometer. The order for the instrument was given to the Repsolds in 1840, but "various circumstances, for which the makers are not responsible, contributed to delay the completion of the instrument, which was not delivered before the winter of 1848."[10] The building to receive it was commenced in March 1849 and completed in the end of the same year. This splendid instrument has a superb object glass of 7½ inches aperture and 126 inches focal length. The makers availed themselves of Bessel's suggestion to make the segments move in cylindrical slides, and of Struve's to have the head attached to a brass tube; the eye piece is set permanently in the axis, and the whole rotates in a cradle attached to the declination axis. They provided a splendid, rigidly mounted, equatorial stand, fitted with every luxury in the way of slow motion, and scales for measuring the displacement of the segments were read by powerful micrometers from the eye end.[11] It is somewhat curious that, though Struve's second suggestion was adopted, his first was overlooked by the makers. But it is still more curious that it was not afterwards carried out, for the communication of automatic symmetrical motion to both segments only involves a simple alteration previously described. But, as it came from the hands of the makers in 1849, the Oxford heliometer was incomparably the most powerful and perfect instrument in the world for the highest order of micrometric research. It so remained, unrivalled in every respect, till 1873; it remains still optically, the most powerful heliometer in the world, and, with a few alterations, it might almost rival the most recent instruments in practical convenience and accuracy. These alterations, all of which could be made without great difficulty, are the following:—

(*a*) Beyond the automatic symmetrical motion above described, the instrument should be fitted with means for adjusting the screens from the eye end (see footnote[6] in last column).

(*b*) The arrangement of the scales should be changed. At present both scales are read separately by separate micrometers, each relatively to a separate fiducial line. What the observer requires is the difference of the readings of the two scales, and this can obviously be most quickly and accurately obtained if the edges of the two scales are brought together, and both are read, relatively to each other, by the same micrometer.

(*c*) The unsatisfactory motion in position angle should be replaced by the action of a pinion (attached to the cradle) in the teeth of a wheel (attached to the tube).[1]

(*d*) The position circle should be read by telescopes or microscopes attached to the cradle, and accessible from the eye end.

(*e*) It would add greatly to the rapidity of work and the ease of the observer if a small declination circle were attached to the cross head, capable of being read from the eye end.

As the transit of Venus of 1874 approached, preparations were set on foot by the German Government in good time; a commission of the most celebrated astronomers was appointed, and it was resolved that the heliometer should be the instrument chiefly relied on. The four long neglected small heliometers made by Fraunhofer were brought into requisition. Fundamental alterations were made upon them:—their wooden tubes were replaced by tubes of metal, means of measuring the focal point were provided, symmetrical motion was given to the slides, scales on each slide were provided instead of screws for measuring the separation of the segments, and both scales were read by the same micrometer microscope, a metallic thermometer was added to determine the temperature of the scales. These small instruments have since done admirable work in the hands of Schur, Hartwig, Kustner, and Elkin.

Russian heliometers.

The Russian Government ordered three new heliometers (each of 4 inches aperture and 5 feet focal length) from the Repsolds, and the design for their construction was superintended by Struve, Auwers

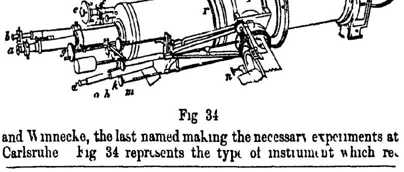


Fig. 34

and Winnecke, the last named making the necessary experiments at Carlsruhe. Fig. 34 represents the type of instrument which re-

---

reading the screws or even the heads from the eye end. Bessel's practice was to unclamp in declination, lower and read off the head, and then restore the telescope to its former declination reading, the clockwork meanwhile following the stars in right ascension. The setting of both lenses symmetrically would under such circumstances be very tedious.

[1] This most important improvement would permit any two stars under measurement each to be viewed in the optical axis of each segment. The optical centres of the segments would also remain at the same distance from the eye piece at all angles of separation. Thus in measuring the largest as well as the smallest angles the images of both stars would be equally symmetrical and equally well in focus. Modern heliometers made with cylindrical slides measure angles over two degrees, the images remaining as sharp and perfect as when the smallest angles are measured.

[2] Bessel found in course of time, that the original corrections for the errors of his screw were no longer applicable. He considered that the changes were due to wear, which would be much lessened if the screws were protected from dust.

[3] The tube being of wood was probably liable to warp and twist in a very uncertain way.

[4] We have been unable to find any published drawing showing how the segments are fitted in their cells.

[5] We have been unable to ascertain the reasons which led Bessel to choose *ivory* planes for the end bearings of his screws. He actually introduced them in the Konigsberg heliometer in 1840, and they were renewed in 1848 and 1850.

[6] A screen of wire gauze placed in front of the segment through which the fainter star is viewed, was employed by Bessel to equalize the brilliancy of the images under observation. An arrangement, afterwards described, has been fitted in modern heliometers for placing the screen in front of either segment by a handle at the eye end.

[7] This heliometer resembles Bessel's, except that its foot is a solid block of granite instead of the ill conceived wooden structure that supported his instrument. The object glass is of 7.4 inches aperture and 123 inches focus.

[8] *Description de l'Observatoire central de Pulkowa*, p. 208.

[9] Steinheil applied such motion to a double image micrometer made for Struve. This instrument suggested to Struve the above mentioned idea of employing a similar motion for the heliometer.

[10] Manuel Johnson, M.A., Radcliffe observer, *Astronomical Observations made at the Radcliffe Observatory, Oxford, in the year* 1850, Introduction, p. ii.

[11] The illumination of these scales is interesting as being the first application of electricity to the illumination of astronomical instruments. Thin platinum wire was rendered incandescent by a voltaic current; a small Swan light and condenser would probably now be found more satisfactory.

[12] This has been recently carried out by Stone, the present Radcliffe observer, on Gill's suggestion.

sulted from their labours The brass tube, strengthened at the bearing points by strong truly turned collars, rotates in the cast iron cradle *q* attached to the declination axis *a* is the eye piece fixed in that axis *b* the micrometer for reading both scales

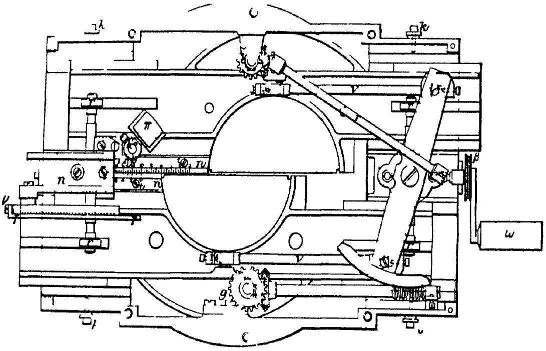


Fig 35

c, *d* are telescopes for reading the position circle *p*, *e* the handle for quick motion in position angle, *f* the slow motion in position angle, *g* the handle for changing the separation of the segments by acting on the bevel wheel *g* (fig 35) *h* is a milled head connected by a rod with *h* (fig 35), for the purpose of interposing at pleasure the prism *π* in the axis of the reading micrometer this enables the observer to view the graduations on the face of the metallic thermometer *ππ* (composed of a rod of brass and a rod of zinc) *i* is a milled head connected with the wheel *ii* (fig 35), and affords the means of placing the screen *s* (fig 34), counterpoised by *w* over either half of the object glass *k* clamps the telescope in declination, *n* clamps it in right ascension and the handles *m* and *l* provide slow motion in declination and right ascension respectively

The details of the internal mechanism of the "head" will be almost evident from fig 35 without description The screw turned by the wheels at *g*, acts in a toothed arc whence as shown in the figure equal and opposite motion is communicated to the slides by the jointed rods *i i* The slides are kept firmly down to their bearings by the rollers *r*, *r*, *r r* attached to axes which are in the middle very strong springs Side shake is prevented by the screws and pieces *k l k k* The scales are at *n n*, they are fastened only at the middle, and are kept down by the brass pieces *t t*

Lord Lindsay's heliometer

A similar heliometer was made by the Repsolds to the order of Lord Lindsay for his Mauritius expedition in 1874 It differed only from the three Russian instruments in having a mounting by the Cookes in which the declination circle reads from the eye end[1] This instrument was afterwards most generously lent by Lord Lindsay to Gill for his expedition to Ascension in 1877[2]

These four Repsold heliometers proved to be excellent instruments easy and convenient in use and yielding results

a small toothed wheel clamped to the rod connected with the driving pinion there was apt to be a torsion of the rod rather than an immediate action Thus the slow motion would take place by jerks instead of with the necessary smoothness and certainty When the heliometer part of Lord Lindsay's heliometer was ac-

quired by Gill in 1879, he changed the manner of imparting the motion in question A square toothed racked wheel was applied to the tube at *r* (fig 34) This wheel is acted on by a tangent screw whose bearings are attached to the cradle, the screw is turned by means of a handle supported by bearings attached to the cradle, and coming within convenient reach of the observer's hand The tube turns smoothly in the racked wheel, or can be clamped to it at the will of the observer This alteration and the new equatorial mounting have been admirably made by Grubb, the result is completely successful The instrument so altered has been in constant use at the Cape Observatory since March 1881 in determining the parallax of the more interesting southern stars

Yale College heliometer.

Still more recently the Repsolds have completed a new heliometer for Yale College, New Haven, United States The object glass is of 6 inches aperture and 98 inches focal length The mounting, the tube, objective-cell, slides, &c, are all of steel[3] The instrument is shown in fig 36 The circles for position angle and declination are read by micrometer microscopes illuminated by the lamp L, the scales are illuminated by the lamp *l* T is part of the tube proper, and turns with the head The tube V, on the contrary, is attached to the cradle, and merely forms a support for the finder Q, the handles at *f* and *p* and the moving ring P The latter gives quick motion in position angle, the handles at *p* clamp and give slow motion in position angle, those at *f* clamp and give slow motion in right ascension and declination *a* is the eye piece *b* the handle for moving the segments *c* the micrometer microscope for reading the scales and scale micrometer, *d* the micrometer readers of the position and declination circles *e* the handle for rotating the large wheel F which carries the screens The hour circle is also read by microscopes and the instrument can be used in both positions (tube preceding and

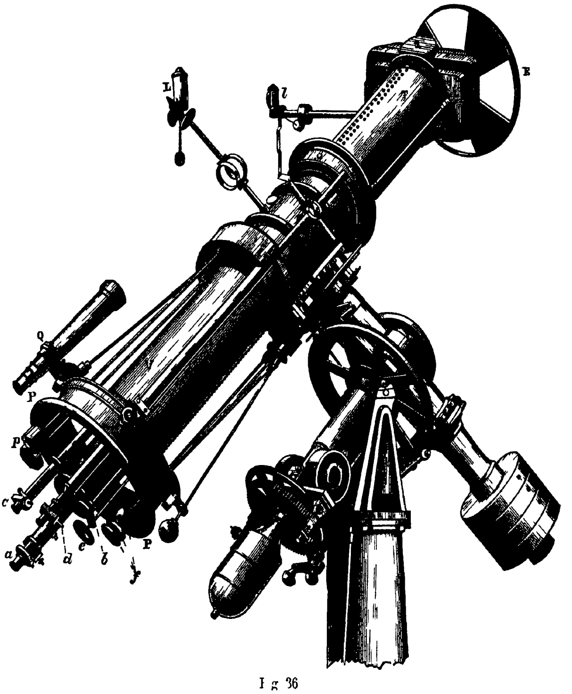


Fig 36

---

[3] The [illegible] object [illegible] the object glass [illegible] in steel cells [illegible] the head of steel for sake of uniformity of [illegible]

following) for the elimination of the effect of flexure on the position angles.

There is very little left to criticize in this instrument. It embraces the results of all knowledge and experience on the subject to the present time. In one point, however, modern heliometers have a disadvantage compared with the older forms. A great advance in accuracy was, no doubt, made when the screw was abandoned as a means both of moving and measuring the displacement of the slides.[1] But it is obviously much quicker to read and record the indication of one screw head than to bisect two or four scale divisions and enter the corresponding readings. Auwers, in his researches on the parallax of 61 Cygni,[2] was able, with the Königsberg heliometer, to make forty pointings in about an hour; it is quick work to make sixteen pointings (reading two divisions on each scale at each pointing) with the modern heliometer in the same time, when attention is paid to the desirable reversals of the segments and of the position circle and the resettings in right ascension and declination. Now time during opportunities of good definition (or otherwise)[3] is too precious to be sacrificed, if it can be saved even by ten fold labour afterwards. Carrington[4] has suggested the possible use of photography to record the readings of astronomical circles, and since his day "Swan lights" and "sensitive dry plates" seems to have brought his suggestion within the range of practice. A special microscope, fitted with an aplanatic photographic objective and a well contrived carrier, might be made automatically to expose a different part of a narrow dry plate, by mere pressure or turning of a button after each bisection. Each plate might easily record the sixteen bisections which constitute a complete measure of two pairs of stars (as in a parallax determination). As it is only necessary to photograph two divisions of each scale, the photographic enlargement of these divisions need only be limited by the sensitiveness of the plates and the power of the illumination to produce a picture in a conveniently short space of time. The plates employed at night could be conveniently developed the following day and measured with a special apparatus at any convenient time and with almost any desired accuracy. Were such a system reduced to practice it would at least double, perhaps treble, an observer's possible output of work.

Reversing prism

Gill has introduced a powerful auxiliary to the accuracy of heliometer measures in the shape of a reversing prism placed in front of the eye piece, between the latter and the observer's eye. If measures are made by placing the image of a star in the centre of the disk of a planet the observer may have a tendency to do so systematically in error from some acquired habit or from natural astigmatism of the eye. But by rotating the prism 90° the image is presented entirely reversed to the eye so that in the mean of measures made in two such positions personal error is eliminated. Similarly the prism may be used for the study and elimination of personal errors depending on the angle made by a double star with the vertical. The best plan of mounting such a prism has been found to be the following. l, l^2 (fig. 37) are the eye lens and field lens respectively of a Merz positive eye piece. In this construction the lenses are much closer together and the diaphragm for the eye is much farther from the lenses than in Ramsden's eye piece. The prism p is fitted accurately into brass slides (care has to be taken in the construction to place the prism so that an object in the centre of the field will so remain when the eye piece is rotated in its adapter). There is a collar, clamped by the screw at S which is so adjusted that the eye piece is in focus when pushed home in its adapter, to this collar. The prism and eye piece are then rotated together in the adapter.

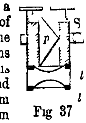


Fig. 37.

On the theory of the heliometer and its use consult Bessel, *Astronomische Untersuchungen*, vol i; Hansen, *Ausführliche Methode mit dem Fraunhofer'schen Heliometer Beobachtungen anzustellen*, Gotha 1827; Chauvenet, *Spherical and Practical Astronomy*, vol ii pp 403-436, Philadelphia and London 1876; Seeliger, *Theorie des Heliometers*, Leipsic 1877; Lindsay and Gill, *Dunecht Publications*, vol ii, Dunecht (for private circulation) 1877; Gill, *Memoirs of the Royal Astronomical Society*, vol xlvi pp 1-172.

Micrometers which Involve the Employment of the Diurnal Motion

Advantage is often taken of the diurnal motion to measure the relative positions of stars. The varieties of reticules and scales that have been employed are far too numerous even for mention in detail. The following are the means and methods by which most work has been done, and they are typical of all the others. In the focus of his meridian telescope Lacaille had a brass diaphragm in which was cut a hole, having parallel, sharp, straight edges of the shape shown in fig. 38. The longer diagonal of the rhomboid so formed was at right angles, and the shorter parallel, to the diurnal motion. The method of observation consisted in noting the instant of ingress and egress of each star which presented itself. The mean of the times thus noted for each star gave the time of its transit over the imaginary line ab, whilst the difference between the instant of ingress and that of egress (converted into arc by the known approximate declination) gave the length of the chord traversed by the star parallel to the imaginary line cd. Hence (the dimensions of the rhomboid being known) the difference of the star's declination from the line cd became known (the observer was of course careful to note whether the star passed to north or south of cd). Thus every star that crossed the field was observed, all their right ascensions were referred to the clock time of passing ab, and all their declinations to that of cd; hence their mutual differences of right ascension and declination were known. In this way, in the short space of ten months, Lacaille observed nearly ten thousand stars at the Cape of Good Hope in the years 1751-52.[5]

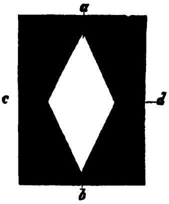


Fig. 38.

Lacaille's rhomboid

Ring micrometer

Fraunhofer's ring micrometer consists of a ring of steel, very truly turned, mounted in a hole cut in a circular disk of glass. The ring is placed in the focus of a telescope, and viewed by a positive eye piece. The observer notes the instants when the two objects enter and emerge from each side of the ring. The only data required for computing the difference of right ascension and declination of the two objects are the times above mentioned, the diameter of the ring, and the approximate declination of one of the objects. The latter is always known. The methods of determining the former and of reducing the observations are to be found in every work on practical astronomy. The ring micrometer has been largely used in observing comets.

Argelander's scale.

Argelander, in making his famous survey of the northern heavens,[6] employed a semicircle of glass, the straight edge of which (truly ground) crosses the centre of the field of view at right angles to the diurnal motion of the stars. Differences of right ascension were directly observed at this edge, whilst differences of declination were noted by strong dark lines drawn at right angles to the edge at each 10 of arc. A telescope of 3 inches aperture with a magnifying power of 10 diameters commanded a field of 3° 20 in declination. One observer was placed at the telescope, another at the clock. The telescope observer marked the instant when the star touched the glass edge by calling sharply the word "eight" or "nine," &c., which also indicated the magnitude; the same observer also noted and recorded the reading of the declination scale (where the star crossed it) without removing his eye from the telescope. The clock observer wrote down the magnitude called out by the telescope observer and the instant by the clock when the word was given. The two records were then compared after the observations of the night were over. In this way Schönfeld and Krueger (Argelander's assistants) observed and catalogued about three hundred thousand stars. The probable error of an observation is about ±0.7 sec in right ascension and ±0.4 in declination.

Bond's mica declinometer

Bond[7] employed a very similar arrangement, differing only from Argelander's in having the scale cut on a sheet of transparent mica $\frac{1}{1000}$th of an inch in thickness. Very oblique illumination was employed, and the divisions and figures were seen bright upon a dark background. The range of declination was limited to 10, the scale was divided to 10, the right ascensions were observed by chronographic registration, and the great refractor of the Cambridge U. S. Observatory (with an aperture of 15 inches and power of 140) was employed. The probable errors in right ascension and declination were found to be ±0.06 sec in right ascension and ±0.6 in declination—results of marvellous accuracy considering the amount of work accomplished in a short time and the faintness (eleven to twelve magnitudes) of the stars observed.

Peters's zones.

We were on the point of criticizing Bond's programme as somewhat too ambitious for realization without cooperation (it would take about twenty six thousand hours of observing to carry out the scheme for the northern hemisphere alone) when we received from Peters of Clinton, U. S., the first twenty maps of a series which will include the whole of the sky between declination +30 and −30. If we consider that all the stars in these maps of the eleventh magnitude or brighter have been observed by a method similar to Bond's, that the enormous additional labour of frequent revision has been undertaken, and all stars visible with a power of 8 in a telescope of 13 inches aperture (about fourteenth magnitude) have been filled in by alignment, *and that all this results from the unaided labour of a single observer*, we find that our ideas of *the possible* have to be modified, when such a man undertakes a work with persistent unity of purpose for more than twenty years (1860–83)

---

[1] Screws, as Auwers's discussion of Bessel's observations (Parallax von 61 Cygni, *Abhandlungen der Königl Akad der Wissenschaften zu Berlin*, 1868) has shown, are apt to wear and change their errors. It is besides undesirable to apply force and friction to a delicate standard of measure.

[2] *Astron Nachrichten*, No 1416.

[3] For example, in determining the diurnal parallax of a planet the most favourable conditions are limited on the one hand by the uncertainties of refraction at large zenith distances and on the other by the small parallax factors for small zenith distances. It would probably be best to secure all the observations between 50° and 60° ZD and this would only be possible with special facilities for reading the scales.

[4] *Monthly Notices R A S*, vol xxx p 46.

[5] Lacaille, *Cœlum Australe Stelliferum*, Paris 1763; and *A Catalogue of 9766 Stars from the Observations of Lacaille*, London 1847.

[6] *Atlas des Nördlichen Gestirnten Himmels*, Bonn 1863, Introduction.

[7] *Annals of the Astronomical Observatory of Harvard College*, vol i part ii.

Berlin declinograph

There is an ingenious mode of registering differences of declination that has been in use at the Berlin Observatory since 1879, and is described by Dr Knorre in the *Zeitschrift fur Instrumentenkunde* for July 1881 The instrument is called a *declinograph* It has a web moved in declination by a quick acting screw, the same screw carries a *travelling pricker or point* The observer having bisected a star by the wire has simply to compress an india rubber ball connected by a flexible tube with a thin metal box made on the principle of the vacuum chamber of an aneroid barometer The expansion of this box so produced brings a sheet of paper in contact with two prickers one the movable pricker before mentioned, the other a fixed pricker The action of the vacuum box also automatically shifts the paper (a long roll) by a small quantity at each observation so that successive observations are recorded in regular order To obtain the observed differences of declination it is then only necessary to measure with a glass scale (divided for the special telescope to 10″) the distance of each record of the moving pricker from the fixed pricker It is found, with this declinograph on the Berlin equatorial that the observed declinations have only a probable error of ±0 9 It is obvious that by using a chronograph in conjunction with this instrument both right ascensions and declinations could be recorded with great accuracy and rapidity

Parallel glass

[illegible] ist [illegible] the cone of rays from the object glass at right angles to the telescope axis One half of this plane remains fixed, the other half is movable When the inclination of the movable half with respect to the axis of the telescope is changed by rotation about an axis at right angles to the plane of division, two images are produced The amount of separation is very small, and depends on the thickness of the glass, the index of refraction, and the focal length of the telescope Secchi (*Comptes Rendus*, xli, 1855, p 906) gives an account of some experiments with a similar micrometer, and Porro (*Comptes Rendus*, xli p 1058) claims the original invention and construction of such a micrometer in 1842 Clausen, however has undoubted priority Helmholtz in his "Ophthalmometer" has employed Clausen's principle, but arranges the plates so that both move symmetrically in opposite directions with respect to the telescope axis Should Clausen's micrometer be employed as an astronomical instrument it would be well to adopt the improvement of Helmholtz

Burton and Grubb (*Monthly Notices*, vol xli p 59), after calling attention to Lamont's paper (*Jahrbuch der K S b München*, p 187) and Littrow's paper (*Proc of Vienna Acad of Sciences*, vol xx p 2[illegible]) on a like subject proceed to describe a most ingenious form of "Ghost Micrometer," in which the *image* of a fine line or lines ruled in (or rather cut through) a silver film deposited on glass is formed at the common focus of an object glass and eye piece of a telescope A faint light being thrown on the outside of the silvered plate there appear bright lines in the field of view We have not had an opportunity of testing this nor Grubb's more recent models but, should it be found possible to produce such images satisfactorily without distortion and with an apparatus convenient and rigid in form, such micrometers will probably supersede the filar micrometer Their absolute freedom from diffraction, the perfect control of the illumination and thickness of the lines, and the accuracy with which it will be possible to construct scales for zone observations will be important features of the new method

For the use of micrometers in connexion with the microscope, see p 277 of the present volume (D GI)

MICRONESIA The term "Micronesia" embraces that region of the Pacific north of the great Melanesian islands, where, either perhaps from a greater or more rapid subsidence, or from the decreasing activity northwards of the coral builders, the islands become, generally speaking, smaller and fewer, and finally cease Accordingly, excepting the Marianas or Ladrones, which are of volcanic origin, and a few isolated instances of elevation in the Carolines, the Micronesian islands, though many of the groups cover a vast area, are almost without exception very small low coral (atoll) formations Besides the LADRONE and CAROLINE ISLANDS (*q v*) Micronesia includes the Marshall and Gilbert groups, and some geographers include the Anson group, a number of small widely scattered islets to the west of Hawaii, the Magellan group farther west, and the Bonin Islands north of the Ladrones[1]

North easterly winds prevail during the winter months over the Marshalls, Ladrones, and Carolines, except in the extreme west, while between May and September the influence of the monsoon causes unsettled weather from the west, with heavy gales In the Gilberts the south-east trade wind brings fine weather at this season

The ethnological features of Micronesia are much more definite than the geographical, for its populations form one great branch of the fair Polynesian race, distinguished from the other by well marked differences in appearance, language, and institutions Its ethnological relations are not thoroughly understood The proximity of Japan and the Philippines on the west and of the Papuan and South Polynesian islands on the south and south east suggests, what in fact we find, a combination of elements in different degrees of fusion In some places the oblique Mongolian eye is noticed, and (along with certain Indo Chinese customs) there is often a scantiness of beard and general "Malay" look which increases westwards, and seems to imply relations with the archipelago subsequent to the departure thence of the pure Polynesians In the Gilberts the traces of Polynesian (Samoan) influences are evident, and are confirmed by tradition Among the Carolines and the Marshalls darker and more savage communities are found, suggesting a Melanesian element, which is further traceable in the Ebon (Marshall) and other languages

Each of the four groups, from long isolation, has developed peculiarities of its own The most advanced were the "Chamorros" of the Ladrones, owing to the greater natural resources of the islands, and perhaps more frequent contact with influences from the west, but as a separate people they no longer exist, having been nearly exterminated by the Spaniards in the 17th century Next in advancement come the Carolines The general type is a well proportioned rather slightly built figure, with small and regular features, head high and well proportioned, but forehead rather retreating, and narrow at the temples, cheek bones and chin slightly prominent, colour somewhat darker than the Polynesians, the Marshalls being darker and more vigorous than the Carolines, while the Gilbert type is still darker and coarser The upper class greatly surpasses the common people in physique and intelligence

There is a peculiar division of society into septs or clans, the membership of which constitutes the closest tie. Persons of the same sept must not intermarry, and when two islands or communities meet in war the members of one sept, however widely separated by distance of space or time, will not injure or fight with each other Each community is usually composed (but there are local differences) of—(1) an upper class of chiefs, from among whom the head (*tamol* or *iros*) is chosen, (2) a lower but still noble class, and (3) common people, mostly without rights of property These last are only allowed one wife. Assemblies of the chiefs everywhere limit the kingly authority In the Marshalls the sovereign has lost his control over many of the atolls, and in the Gilberts the above distinctions have nearly disappeared, the headship has lapsed, and, especially in the southern islands, the man of largest substance is the most powerful, and sometimes establishes a local supremacy Here and there are traces, as in Tonga, of a spiritual sovereign, the descendants probably of a conquered dynasty Succession is through the female side, which assures to women a certain position, and leads besides to some curious results (see paper by Kubary in *Das Ausland*, 1880, No 27) The upper class are the keepers of traditions, boat builders, leaders of expeditions, tattooing is generally done by them, the amount increasing with a man's rank, the custom here still has definite religious associations Both sexes are tattooed The people are singularly amiable and well disposed, but will repay ill usage with treachery The women (although chastity is not expected before marriage) are somewhat more moral than the Polynesians, and are treated with respect, as are the aged The natives are polite and hospitable to strangers (except on the poorer and ruder islands), bright and intelligent, active traders, expert cultivators and fishermen They have a hand loom from which beautiful fabrics of banana, hibiscus, and other fibres are produced The Marshall Islanders are the boldest and most skilful navigators in the Pacific Their voyages of many months' duration, in great canoes sailing with outrigger to windward, well provisioned, and depending on the skies for fresh water, help to show how the Pacific was colonized They have a sort of chart, *medo*, of small sticks tied together, representing the positions of islands and the directions of the winds and currents A two edged weapon, of which the blade is of sharks' teeth, and a defensive armour of braided sennit, are also peculiar to the islands, a large adze, made of the *Tridacna gigas*, was formerly used in the Carolines, probably by the old builder race

---

[1] These islands, which contain a mixed immigrant population, are claimed, and have been recently surveyed, by Japan But they were annexed to England by Captain Beechey in 1827 (See Von Kittlitz, *Denkwürdigkeiten einer Reise nach* . *Mikronesien*, &c, vol ii)

The languages of Micronesia, though grammatically alike, differ widely in their vocabularies They have the chief characteristics of the Polynesian, with Malay affinities, and peculiarities such as the use of suffixes and inseparable pronouns and, as in Tagal, of the infix to denote changes in the verb, in the west groups there is a tendency to closed syllables and double consonants, and a use of the palatals *ch*, *j*, *sh*, the dental *th*, and *s* (the last perhaps only in foreign words), which is alien to the Polynesian These letters are wanting in the Gilbert language, which differs considerably from all the others, and has much greater affinities with the Polynesian

The religious myths are generally identifiable with the Polynesian, but a belief in the gods proper is overshadowed by a general deification of ancestors, who are supposed from time to time to occupy certain blocks of stone, set up near the family dwelling, and surrounded by circles of smaller ones These stones are anointed with oil, and worshipped with prayer and offerings, and are also used for purposes of divination in which, and in various omens, there is a general belief In the Marshalls, in place of these stones, certain palm trees are similarly enclosed The spirits also sometimes inhabit certain birds or fishes, which are then *tabu*, as food, to the family, but they will help to catch them for others All this closely recalls the *karwars* or ancestral images of New Guinea Temples are very rare, though these blocks of coral are sometimes surrounded by a roofless enclosure opening to the west The bodies of the dead, and sometimes even of the sick, are despatched to sea westwards, with certain rites, those of the chiefs, however, are buried, for the order has something essentially divine about it their bodies therefore are sacred, and their spirits naturally assume the position above described Such a belief greatly strengthens the king s authority, for the spirits of his ancestors are necessarily more powerful than any other spirits Thus too it comes that the chiefs, and all belonging to them, are tabu as regards the common people There are various other subjects and occasions of tabu but the institution has not the oppressive and all pervading character which it has in Polynesia Its action is often economical or charitable, *e g*, the ripening cocoa nuts are tabu as long as the bread fruit lasts thus securing the former for future use, or it is put on after a death, and the nuts thus saved are given to the family—a kindness to them, and a mark of respect for the dead

The flora of the Gilbert and Marshall groups is of the usual oceanic character, with close Indo-Malay affinities It is much poorer than that of the Carolines,[1] with its Moluccan and Philippine elements, and this again is surpassed by that of the Ladrones In the Gilberts the scattered woods of cocoa palm and *Pandanus* have little undergrowth, while the south Marshalls, being within the belt of constant precipitation, have a dense growth of (mostly) low trees and shrubs, with here and there a tropical luxuriance and variety unusual on atolls The *Pandanus* grows wild profusely, and is of exceptional importance, being the chief staple of food, so that the cocoa nut, which, however, flourishes chiefly in the Gilberts, is used mainly to produce oil for exportation The bread fruit grows chiefly in the south Marshalls The taro (*Arum cordifolium* and others) is cultivated laboriously, deep trenches being cut in the solid rock for its irrigation, but this and other plants of cultivation, and indeed the vegetation generally, fall off in number and quality northwards Various vegetables are grown on soil imported for the purpose Marine plants are rare Wilkes found on Makin Island, Gilbert group, a "fruit resembling the gooseberry," called "teiparu, from which a preserve is made This seems very like the tipari or Cape gooseberry of India (*Physalis peruviana*). And their *karaka*, a drink made from the sap of the flower stalk of the cocoa palm (unfermented before the arrival of Europeans), recalls the arrack of southern Asia

The fauna, like the flora, becomes poorer eastwards, birds being much more numerous on the high islands than on the atolls, where the few are chiefly aquatic On Bonabe (Puynipet) out of twenty-nine species eleven are sea birds, and of the remaining eighteen seven are peculiar to the island From the Pelews fifty six species are recorded (twelve peculiar), and from the neighbouring Mackenzie group (Ulithi) twenty (six peculiar) Yet curiously no species is recorded common to these two groups and peculiar to them The common fowl is found everywhere, wild or tame, and in some places is kept for its feathers only The rat and a *Pteropus* are the only indigenous land mammals The Indian crocodile is found as far east as the Pelews There are five or six lizards, including a *Gecko* and *Ablephorus* Insects are numerous, but of few kinds Scorpions and centipedes are common, but are said to be harmless

The houses in the Gilberts and Marshalls (much less elaborate than in the Carolines) consist merely of a thatched roof resting on posts or on blocks of coral about 3 feet high, with a floor at that level, which is reached from an opening in the centre On this the principal people sleep and it serves as a storehouse inaccessible to rats, which infest all the islands

The Marshall archipelago consists of two nearly parallel chains of atolls, from 100 to 300 miles apart the west known as Ralik, the east as Ratak They lie between 4° 30 and 12° N, and between 165° 15 and 172° 15 E and run about N N W and S S E They were discovered in 1529 by Saavedra, who, observing the fine tattooing of the inhabitants (the first allusion to the practice in the Pacific), called them Los Pintados Among modern voyagers Wallis first visited them in 1767 Captains Marshall and Gilbert reached them in 1788, and Kotzebue (1816) explored them more thoroughly Each group contains fifteen or sixteen atolls, which range from 2 to 50 miles in circumference An anomalous feature is reported on some of them, viz, that the greater proportion of land, or at all events of soil, is not found as usual on the windward side of the lagoon, for the prevailing north east wind sweeps it is said, the materials of which the soil of such islands is composed across to the lee side Jaluit Island is the commercial emporium of the whole region There is a curious tradition on Ebon Island of the Darwinian fact that the atoll once formed the barrier reef of an island now sunk beneath the lagoon The population of Ratak is about 6000, of Ralik 4000, there is little intercourse between the two groups

The Gilbert archipelago, discovered by Byron in 1765, is geographically a south continuation of the Marshalls, the channel separating them being 50 leagues wide It lies between 2° 40′ S and 3° 20 N, and between 172° 30 and 177° 15 E, and contains sixteen atolls, not including two hilly islands, Banaba and Nawodo, which lie 5° to 6° to the west Several have good anchorages inside the lagoon, with entrances on the lee side On some the lee or west reef is wanting, owing to the abrading force of the west storms During these large trees are washed ashore, their roots containing pieces of fine basalt of which implements are made There is a far larger proportion of land to submerged reef and lagoon than in the Marshalls, the land sometimes rising 20 feet above the sea, whereas in the Marshalls the average level of the reef rock is less than a foot above the surface but though the supply of fresh water is exceptionally great, in fact enough for the luxury of a bath, the soil (especially in the south) is very much less productive Yet the population about 50,000, is exceptionally dense The usual scattered houses are replaced by compact rows of roofs which, shaded by cocoa palm, and each with its boat shed below, line the shore Their numbers are unchecked either by the constant practice of abortion or by fighting, to which they are much addicted, their weapons being more formidable than those of their neighbours This exceptional vigour may be due to the decidedly hybrid character of the race Hawaiian missionaries, under American superintendence, have laboured here since 1857

See also Findlay s *Sailing Directions for the North Pacific* Roper s *North Pacific Pilot and Nautical Magazine* vols xxxi and xxxv Other authorities are Gerland in *Waitz s Anthropologie der Naturvölker* vol v Meinicke *Die Inseln des Stillen Oceans* Hale s *Ethnography and Philology of Wilkes s U S Exploring Expedition* Kotzebue and Chamisso *Entdeckungsreise in die Sudsee*, *Proc Zool Soc*, 1872 and 1877 (C T)

MICROPHONE See TELEPHONE

---

[1] About 180 species have been observed on Kusaie, one fourth of all the plants being ferns.

MICROSCOPE

THE microscope is an optical instrument for the examination of minute objects or parts of objects, which enlarges the visual pictures formed upon the retina of the observer by the rays proceeding from them.

Microscopes are distinguished as *simple* or *compound*. In the former, the rays which enter the eye of the observer come from an object brought near to it after refraction through either a single lens or a combination of lenses acting as a single lens,—its action as a "magnifier" depending on its enabling the eye to form a distinct image of the object at a much shorter distance than would otherwise be possible. The latter consists of at least two lenses, so placed relatively to the object, to the eye, and to one another that an enlarged image of the object, formed by the lens placed nearest to it (the "object glass"), is looked at through the lens nearest the eye (the "eye glass"), which acts as a simple microscope in "magnifying" it, so that the compound microscope may be described as a simple microscope used to look at an enlarged image of the object, instead of at the object itself.

History of the Simple Microscope.—Any solid or liquid transparent medium of lenticular form having either one convex and one flat surface or two convex surfaces whose axes are coincident, may serve as a "magnifier,"—what is essential being that it shall have the power of so refracting the rays which pass through it as to cause widely diverging rays to become either parallel or but slightly divergent. Thus if a minute object be placed on a slip of glass, and a single drop of water be carefully placed upon it the drop will act as a magnifier in virtue of the convexity of its upper surface; so that when the eye is brought sufficiently near it (the glass being of course held horizontally, so as not to distort the spherical curvature of the drop) the object will be seen much enlarged. And if a small hole be made in a thin plate of metal, and a minute drop of water be inserted in it, this drop, having two convex surfaces, will serve as a still more powerful magnifier. There is reason to believe that the magnifying power of transparent media with convex surfaces was very early known. A convex lens of rock crystal was found by Layard among the ruins of the palace of Nimrud. And it is pretty certain that after the invention of glass, hollow spheres blown of that material and filled with water were commonly used as magnifiers (comp. vol. xiv. p. 577). The perfection of gem cutting shown in ancient gems, especially in those of very minute size, could not have been attained without the use of such aids to the visual power; and there can be little doubt that the artificers who could execute these wonderful works could also shape and polish the magnifiers best suited for their own or others' use. Though it is impossible to say when convex lenses of glass were first made by grinding, it is quite certain that they were first generally used to assist ordinary vision as "spectacles," the use of which can be traced back nearly six centuries; and not only were spectacle makers the first to produce glass magnifiers (or simple microscopes), but by them also the telescope and the compound microscope were first invented. There seems no reason to believe, however, that lenses of very high magnifying power (or short focus) were produced until a demand for them had been created by the introduction of the compound microscope, in which such lenses are required as "object glasses;" and the difficulty of working lenses of high curvature with the requisite accuracy led in the first instance to the employment of globules made by fusing the ends of threads of spun glass. It was in this way that Robert Hooke shaped the minutest of the lenses with which he made many of the numerous discoveries recorded in his *Micrographia*, and the same method was employed by the Italian microscopist Father Di Torre. It seems to have been Leeuwenhoek that first succeeded in grinding and polishing lenses of such short focus and perfect figure as to render the simple microscope a better instrument for most purposes than any compound microscope then constructed,—its inferiority in magnifying power being more than counterbalanced by the superior clearness of the retinal picture. And, in despair of any such modification in the compound form as should remove the optical defects which seemed inherent in its plan of construction, scientific opticians and microscopic observers alike gave their chief attention for a considerable period to the improvement of the simple microscope. In order that the nature of these improvements may be understood, the principle of its action must be first explained.

The normal human eye has a considerable power of self adjustment, by which its focal length is so varied that it forms equally distinct pictures of objects brought within ordinary reading distance (say 10 inches) and of objects whose distance is many times that length,—the size of the visual picture of any object diminishing, however, with the increase in the distance to which it is removed, and the amount of detail distinguishable in it following the same proportion. Thus a man who looks across the street at a placard posted on the opposite wall may very distinctly see its general form and the arrangement of its heading, and may be able to read what is set forth in its largest type, whilst unable to separate the lines, still more to read the words, of what is set forth below. But by crossing the street so as to bring his eye nearer the picture he finds himself able to read the smaller type as easily as he before read the larger,—the visual picture on his retina having been magnified, say 10 times in linear dimension, by the reduction of the distance of his eye from 40 feet to 4. Similarly, if he holds a page of excessively minute type at arm's length (say 40 inches) from his eye, he may be unable to read it, not because his eye does not form a distinct retinal picture of the page at that distance, but because the details of that picture are too minute for him to distinguish them. But if he brings the page from 40 inches to 10 inches distance, he may be able to read it without difficulty,—the retinal picture being enlarged four times linear (or sixteen times superficial) by this approximation. Now the rays that enter the eye from each point of a remote object diverge so little as to be virtually parallel; but the divergence increases with the approximation of the object to the eye, and at 10 inches the angle of their divergence is as wide as permits the ordinary eye to bring them to a focus on the retina. When the object is approximated more closely, an automatic contraction of the pupil takes place, so that the most diverging rays of each pencil are cut off, and a distinct picture may be formed (though not without a feeling of strain) when the object is (say) from 5 to 8 inches distant,—giving still greater minuteness of visual detail in conformity with the increase of size. A further magnifying power may be obtained without the interposition of any lens, by looking at an object, at 2 or 3 inches distance, through a pin hole in a card; for by thus cutting off the more divergent rays of each pencil, so as to admit only those which can be made to converge to a focus on the retina at that distance, a distinct and detailed picture may be obtained, though at the expense of a great loss of light. Moreover, although an ordinary eye does not form a distinct picture of an object at less than from 10 to 6 inches distance, a "myopic" or "short sighted" eye (whose greater refractive power enables it to bring rays of wider divergence to a focus on the retina) may form an equally distinct picture of an object at from 5 to 3 inches distance, and, as the linear dimensions of that picture will be double that of the preceding, the object will be "magnified in that proportion, and its details more clearly seen

The effect of the interposition of a convex lens between the eye and an object nearly approximated to it primarily consists in its reduction in the divergence of the rays of the pencils which issue from its several points, so that they enter the eye at the moderate divergence which they would have if the object were at the ordinary nearest limit of distinct vision And, since the shorter the focus of the lens the more closely may the object be approximated to the eye, the retinal picture is enlarged, causing the object to appear magnified in the same proportion Not only, however, are the component rays of each pencil brought from divergence into convergence, but the course of the pencils themselves is changed, so that they enter the eye under an angle corresponding to that under which they would have arrived from a larger object situated at a greater distance, and thus, as the picture formed upon the retina by the small object *ab*, fig 1, corresponds in all respects with that which would have been made by the same object AB of several times its linear dimension viewed at the nearest ordinary limit of distinct vision, the object is seen (by the formation of a "virtual image) on a magnified scale

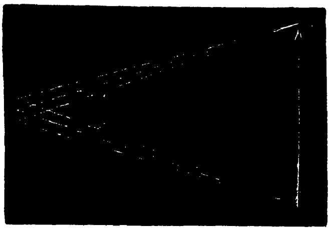


Fig 1 —Action of Simple Microscope

It is obvious that the "magnifying power of any convex lens so used is measured by the ratio between the dimensions of the retinal picture formed with its assistance and those of the picture formed by the unaided eye Thus, if by the use of a convex lens having 1 inch focal length we can form a distinct retinal image of an object at only an inch distance, this image will have ten times the linear dimensions of that formed by the same object at a distance of 10 inches, but will be only eight times as large as the picture formed when the object can be seen by ordinary vision at 8 inches distance, and only four times as large as the picture of the same object formed by a myopic eye at a distance of 4 inches It is usual to estimate the magnifying power of single lenses (or of combinations that are used as such) by the number of times that their focal length is contained in 10 inches,—that of 1 inch focus being thus taken as ten times that of $\frac{1}{10}$ inch as one hundred times, and so on But the rule is obviously arbitrary, as the actual magnifying power varies in each individual with the nearest limit of distinct vision Thu

lens will be only 4 and 40 respectively The amplifying power of every single convex lens, however, is impaired (1) by that inability to bring to the same focus the rays which fall upon the central and the marginal parts of its surface which is called "spherical aberration," and (2) by that dispersion of the rays of different wave lengths, in virtue of their different refrangibilities, which produces coloured fringes around the points and lines of the visual picture, and is therefore called "chromatic aberration" (see LIGHT) These aberrations increase with the "angle of aperture" given to the lens, that is, with the proportion between the diameter of its actual "opening" and the focal distance of the object, and thus, when a single lens of very short focus is used in order to gain a high magnifying power, such a reduction of its aperture by a perforated diaphragm or "stop ' becomes necessary (in order, by excluding the peripheral rays, to obtain tolerable "definition" with freedom from false colour) that the amount of light admitted to the eye is so small as only to allow the most transparent objects to be thus viewed, and these only very imperfectly In order to remedy this drawback, it was proposed by Sir D Brewster to use instead of glass, in the construction of simple microscopes, such transparent minerals as have high refractive with low dispersive power, in which case the same optical effect could be obtained with lenses of much lower curvature, and the aperture might be proportionately enlarged This combination of qualities is found in the diamond, whose index of refraction bears such a proportion to that of glass that a diamond lens having a radius of curvature of 8 would give the same magnifying power as a glass lens whose radius of curvature is 3, while the ' longitudinal aberration ' (or distance between the foci of central and of marginal rays) would be in a diamond lens only one ninth of that of a glass lens having the same power and aperture Putting aside, however, the costliness of the material and the difficulty of working it a source of imperfection arises from a frequent want of homogeneousness in the diamond crystal, which has proved sufficient to make a lens worked from it give a double or even a triple image Similar attempts made by Mr Pritchard with sapphire proved more successful, and, as a sapphire lens having a radius of curvature of 5 has the same focus and gives the same magnifying power as a crown glass lens having a radius of 3, it was found to bear a much larger aperture without serious impairment by either spherical or chromatic aberration As the sapphire, however, possesses the property of double refraction, the duplication of the markings of the object in their retinal image constitutes a very serious drawback to the utility of lenses constructed of this mineral for, though the double refraction may be reduced almost to nothing by turning the convex side of the lens towards the object, yet, as this is the worst position in regard to spherical aberration, more is lost than is gained Fortunately, however, for biological investigators working with simple microscopes, the introduction of the Wollaston doublet superseded the necessity of any further attempts at turning costly jewels to account as high power magnifiers

Wollaston Doublet—This consists of a combination of two plano convex lenses, whose focal lengths (as directed by Dr Wollaston) should be as 3 to 1, with their plane sides turned towards the object,—the smaller lens being placed lowest, and the upper lens at a distance of one and a half times its focal length above it This construction, however, has been subsequently improved—(1) by the introduction of a perforated diaphragm between the lenses (2) by a more effective adjustment of the distance between the two lenses, which seems to be most satisfactory when it equals the difference of their respective focal lengths, allowance being made for their thickness and (3) by the division of the power of the lower lens (when a shorter focus than $\frac{1}{10}$ inch is required) into two, so as to form a "triplet' When combinations of this kind are well constructed, spherical aberration is almost wholly got rid of, and chromatic dispersion is so slight that the angle of aperture may be considerably enlarged without much sacrifice of distinctness Such "doublets" and "triplets," having been brought into use in England while the compound microscope still retained its original imperfections, proved very serviceable to such as were at that time prosecuting minute biological investigations for example, the admirable researches of Dr Sharpey on ciliary action in animals (1830-35) and Mr Henry Slack's beautiful dissections of the elementary tissues of plants, as well as his excellent observations on vegetable cyclosis (1831), were made by their means No one, however, would now use Wollaston "doublets" or "triplets" of high power in place of a compound achromatic microscope, and for the simple microscopes of low power that are useful either for dissecting or for picking out minute specimens (such as diatoms) other constructions are preferable, as giving a larger field and more light As a hand magnifier the "Coddington' lens—which is a sphere of glass with a deep groove ground out of its equatorial portion—has many advantages[1] By making this groove sufficiently deep, both spherical and chromatic aberrations can be rendered almost insensible, and, as the rays falling on any part of the spherical surface can only pass to the eye either through or near the centre, the action of every part of that surface is the same, so that the image of the object will be equally distinct (when properly focussed) whether its parts lie nearer to the axis of the sphere or more remote from it, or the axis be itself turned to one side or the other Again, it was mathematically shown by Sir John Herschel in 1821 that by the combination of a meniscus with a double convex lens—the four surfaces of these lenses having certain proportionate curvatures—spherical aberration could be entirely extinguished for rays parallel to the axis, the combination being thus an "aplanatic" doublet, while another combination, which he termed a "periscopic" doublet, gives a remarkable range of oblique vision with low powers, and almost entirely extinguishes chromatic aberration, although at the expense of residual spherical aberration These combinations have been mounted both as hand magnifiers and as single microscopes, for both which purposes they are much superior to single lenses of the same magnifying power But such combinations have been greatly improved by the introduction of concaves of flint glass, so as to render them achromatic as well as aplanatic and nothing, according to the writer's experience, can now be used with greater advantage for all the purposes answered either by the simple microscope or the hand magnifier than Browning's 'platyscopic' lenses or the "achromatic doublets" of Steinheil of Munich Each of these combinations gives a large flat field, with plenty of light, admirable definition, and freedom from false colour

At the period when "doublets" of very short focus were used in order to obtain high magnifying power, it was requisite to mount these on such a stand as would enable the focal adjustment to be made and would admit the use of a special illuminating apparatus with great exactness But now that comparatively low powers only are employed the ordinary rack and pinion movement is quite sufficient for their focal adjustment, and nothing more is required for the illumination of the object than a concave mirror beneath the stage when it is transparent, and a condensing lens above when it is opaque The various patterns of simple microscope now made by different makers vary in their construction, chiefly in regard to portability, the size of their stages, and the mode in which "rests" or supports to the hands are provided These, in Continental instruments, are very commonly attached to the stage, but, unless the stage itself and the pillar to which it is fixed are extremely massive, the resting of the hands on the supports is apt to depress the stage in a degree that affects the focal adjustment, and where portability is not an object it seems better that the hand supports should be independent of the stage For a laboratory microscope, the pattern represented in fig 2 has been found very convenient,—the framework being of mahogany or other hard wood, the stage being large enough to admit a dissection or carry a water trough of considerable size, and the bent arm that carries the "powers" being made capable of reversion, so as to permit the use of lenses of very long as well as of very short focus As it is desirable that the stage should not be acted on chemically by sea water, acids, or other reagents, it may be made either of a square of plate glass or of a plate of ebonite with an aperture in the middle, and either of these may be made to slide in grooves in the side supports, so that one may be substituted for the other The arm may be easily made (if desired) to carry the body of a compound microscope so as to apply it to the examination of objects dissected or otherwise prepared under the simple microscope, without transferring them to another instrument A portable form of simple microscope is shown in fig 30

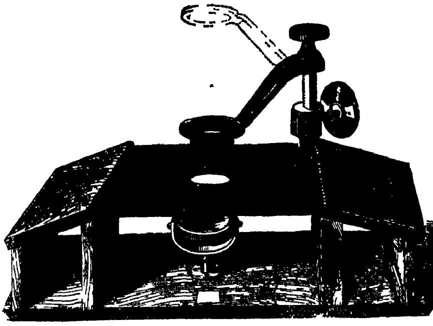


Fig 2 —Laboratory Dissecting Microscope

Compound Microscope —The placing of two convex lenses in such relative positions that one should magnify an enlarged image of a small near object formed by the other naturally soon followed the invention of the telescope, and seems to have first occurred to Hans Zansz or his son Zacharias Zansz, spectacle makers at Middelburg in Holland, about 1590 One of their compound microscopes, which they presented to Prince Maurice, was in the year 1617 in the possession of Cornelius Drebell of Alkmaar, who then resided in London as mathematician to king James I In order to make clear the successive stages by which the rude and imperfect microscope of that period has, after remaining for two centuries unimproved in any essential particular, been developed within the last half-century into one of the most important instruments of scientific research that the combination of theoretical acumen and manipulative skill has ever produced, it is necessary to explain the principle of its construction, and to show wherein lay the imperfection of its earlier form.

In its simplest construction, as already stated, the compound microscope consists of only two lenses,—the "object glass" CD, fig 3, which receives the light rays direct from the object AB placed near it, and forms an enlarged but reversed image A B′ at a greater distance on the other side, and the "eye glass" LM, which receives the rays that diverge from the several points of this image as if they proceeded from the points of an actual object occupying the position and enlarged to the dimensions A′B′, and brings these to the eye at E, so altering their course as to act as a simple microscope in magnifying that image to the observer It was early found useful, however, to interpose another lens FF, fig 4 (the "field glass"), between the object glass and the image formed by it, for the purpose of giving such a slight convergence to the pencil of rays as shall reduce the dimensions of the image, and thus allow a larger part of it to come within the range of the eye glass, so that more of the object can be seen at once. And it was soon perceived that the eye glass and the field glass might be advantageously combined into an "eye piece," in which a perforated diaphragm might be inserted at the focal plane of the image (*i e*, in the focus of the eye glass), so as, by cutting off the peripheral portion of the field of view, to limit it to what can be seen with tolerable distinctness

---

[1] It is difficult to understand how the name of Coddington came to be attached to the grooved sphere, seeing that he neither was nor claimed to be the inventor of it Dr Wollaston's first "doublet" consisted of a pair of plano convex lenses with their plane surfaces opposed to each other, and a diaphragm with central aperture placed between them Sir D Brewster showed that this construction is most advantageous when the two lenses are hemispheres, and the central aperture between their two plane surfaces is filled up by a transparent cement having the same refractive index as glass And from this the transition is obvious to the grooved sphere, which had been made for Sir D Brewster long before the high commendation it received from Mr Coddington brought it into general repute

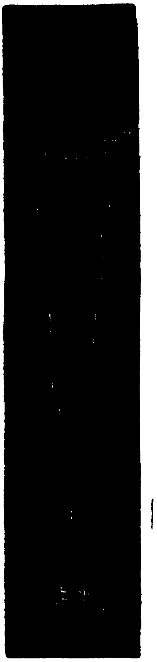


FIG 3 —Diagram of Simplest Form of Compound Microscope

FIG 4 —Diagram of Complete Compound Microscope

It is obvious that the magnifying power of such an instrument would depend (1) on the proportion between the size of the image formed at BB and that of the actual object, and (2) upon the magnifying power of the eye glass And further the proportion which the size of the image bears to that of the object depends upon two factors,—(1) the focal length of the object glass, and (2) the distance between the object glass and the plane BB occupied by the image it forms If we diminish the focal length of the object glass, the object must be brought nearer to it, so that, while the distance of the image on the other side remains unchanged, that distance comes to bear a larger proportion to the distance of the object, and the size of the image is augmented in a corresponding ratio On the other hand, the object glass remaining unchanged, the distance at which it forms the image of the object can be increased by a lengthening of the tube of the microscope, and, as this involves a shortening of the distance between the object-glass and the object, the proportion which the former bears to the latter is augmented, and the image is correspondingly enlarged Thus an increase in the magnifying power of the compound microscope may be gained in three modes, which may be used either separately or in double or triple combination,—viz, (1) shortening the focus of the object glass, (2) lengthening the tube of the microscope, and (3) increasing the magnifying power of the eye glass by shortening its focus This, it may be remarked, also lengthens the distance of the image from the object glass, by bringing the focal plane BB nearer the eye glass The second of these methods was not unfrequently used in the older microscopes, which were sometimes made to draw out like telescopes, so as to increase the amplifying power of their object-glasses But, whilst very inconvenient to the observer, such a lengthening of the one distance involved such a shortening of the other as greatly impaired the distinctness of the image by increasing the aberrations of the object-glass, so that this method came to be generally abandoned for one of the other two

When lenses of from 1 to 4 inches focus were used as object glasses, and their apertures were restricted by a stop to the central part of each, tolerably distinct images were given of the larger structural arrangements of such objects as sections of wood or the more transparent wings of insects,—which images would bear a further moderate enlargement by the eye glass without any serious deterioration either by want of definition or the introduction of colour fringes But when lenses of less than 1 inch focus were employed in order to obtain a higher magnifying power, the greater obliquity of the rays so greatly increased their aberrations that defective definition and the introduction of false colours went far to nullify any advantage obtainable from the higher amplification, while the limitation of the aperture required to keep these aberrations within even moderate limits occasioned such a loss of light as most seriously to detract from the value of the picture On the other hand, the use of deeper eye pieces to enlarge the images formed by the object glasses not only brought out more strongly all the defects of those images, but introduced a new set of errors of their own, so that very little was gained by that mode of amplification Hence many of the best of the older microscopists (notably **LEEUWENHOEK**, *q v*) made some of their most valuable discoveries by the use of the simple microscope, and the amount of excellent work thus done surprises every one who studies the history of microscopic inquiry This was still more the case, as already stated, when the use of single lenses of very short focus was superseded by the introduction of the Wollaston doublet And the substitution of these doublets for the single lenses of object glasses, while the single lens of the eye glass was replaced by a Herschel s aplanatic doublet, and the field glass was a convex lens whose two curves had the proportion of 1 6 (the form of least spherical aberration), constituted the greatest improvement of which the instrument seemed capable in pre-achromatic times[1]

It has been only within the last sixty years (1820–30) that the microscope has undergone the important improvement which had been worked out by Dollond in the refracting telescope more than sixty years previously,—namely, the correction of the chromatic aberration of its objectives by the combination of concave lenses of flint-glass with convex lenses of crown, while their spherical aberration is corrected by the combination (as in Herschel's aplanatic doublet) of convex and concave surfaces of different curvatures The minute size and high curvature of the lenses required as microscopic objectives were long considered as altogether precluding the possibility of success in the production of such combinations, more especially as the conditions they would have to meet differ altogether from those under which telescopic object glasses are employed For the rays from distant objects fall upon the latter with virtual parallelism, and the higher the power required the longer is the focus given to them, and the smaller is the deflexion of the rays In the microscope, on the other hand, the object is so closely approximated to the objective that the rays which proceed to it from the latter have always a very considerable divergence, and the deflexion to which they are subjected increases with that reduction of the focal length of the objective which is the necessary condition of the increase of its magnifying power And thus, although the telescopic "triplet" worked out by Dollond (consisting of a double concave of flint glass, interposed between two double-convex lenses of crown) can be so constructed as to be not only completely aplanatic (or free from spherical aberration) but almost completely achromatic (or free from chromatic aberration), this construction is only suitable for microscopic objectives of long focus and small angular aperture, the rays falling on which have but a very moderate divergence And though, as will presently appear, some of the early attempts at the achromatization of the microscope were made in this direction, it was soon abandoned for other plans of construction, which were found to be alike theoretically and practically superior

---

[1] This combination was made in the first microscope of which the writer became possessed, about the year 1830 and he well recollects the great superiority to any compound microscope of the old construction which was proved by its power of separating the lines on the *Menelaus* scale, and of bringing into view the details of the structure of animalcules, with a clearness that only an achromatized object glass could surpass

It seems to have been by Professor Amici, then of Modena, about 1812, that the first attempts were made at the achromatization of microscopic objectives, but, these attempts not proving successful, he turned his attention to the production of a reflecting microscope, which was a decided improvement upon the non achromatized compound microscopes then in use In the year 1820, however, the subject was taken up by Selligues and Chevalier of Paris, who adopted the plan of superposing three or four combinations, each consisting of a double-convex of crown cemented to a plano concave of flint The back combination (that nearest to the eye) was of somewhat lower power than those placed in front of it, but these last were all of the same focus, and no attempt was made by those opticians to vary the construction of the several pairs thus united, so as to make them correct each others' aberrations Hence, although a considerable magnifying power could be thus obtained, with an almost complete extinction of chromatic aberration, the aperture of these objectives could not be greatly widened without the impairment of the distinctness of the image by a "coma" proceeding from uncorrected spherical aberration

In ignorance, it would appear, of what was being done by the Paris opticians, and at the instigation of Dr Goring (a scientific amateur), Mr Tulley—well known in London as an able constructor of telescopic objectives—began, about the year 1824, to work object glasses for the microscope on the telescopic plan After many trials[1] he succeeded, in 1825, in producing a triplet of $\frac{9}{10}$ inch focus, admitting a pencil of 18°, which was so well corrected as to perform very satisfactorily with an eye piece giving a magnifying power of 120 diameters He afterwards made a similar triplet of shorter focus, which, when placed in front of the previous one, increased the angle of the transmitted pencil to 38°, and bore an eye piece giving a magnifying power of 300 diameters These triplets are said by Mr Ross to have never been exceeded by any similar combinations for accurate correction throughout the field

Having come into possession, at the end of 1826, of an objective of Chevalier's construction, Mr J J Lister carefully examined its properties, and compared them with those of Tulley's triplets, and this comparison having led him to institute further experiments he obtained results which were at first so conflicting that they must have proved utterly bewildering to a less acute mind,[2] but which finally led him to the enunciation of the principle on which all the best microscopic objectives are now constructed For he discovered that the performance of such composite objectives greatly depends upon the relative position of their component combinations,—the effect of the flint plano-concave upon the spherical aberration produced by the double convex of crown varying remarkably according to the distance of the luminous point from the front of the objective If the radiant is at a considerable distance, the rays proceeding from it have their spherical error under-corrected, but, as the source of light is brought nearer to the glass, the flint lens produces greater proportionate effect, and the under correction diminishes, until at length a point is reached where it disappears entirely, the rays being all brought to one point at the conjugate focus of the lens This, then, is one aplanatic focus If, however, the luminous point is brought still nearer to the glass, the influence of the flint continues for a time to increase, and the opposite condition of over-correction shows itself But, on still further approximation of the radiant, the flint comes to operate with less effect, the excess of correction diminishes and at a point still nearer to the glass vanishes, and a second aplanatic focus appears From this point onwards under-correction takes the place of over correction, and increases till the object touches the surface of the glass As every such doublet, therefore, has two aplanatic foci for all points between which it is over corrected, while for all points beyond it is under corrected, the optician is enabled to combine two or more doublets with perfect security against spherical error This will be entirely avoided if the rays be received by the front glass from its shorter aplanatic focus, and transmitted through the back glass in the direction of its longer aplanatic pencil By the approximation of the two doublets over correction will be reduced, while their separation will produce under correction, and thus, by merely varying the distance between two such combinations, the correction of the spherical error may be either increased or diminished according to a definite rule Slight defects in one glass may thus be remedied by simply altering its position in relation to the other,—an alteration which may be made with very little disturbance of the colour correction This important principle was developed and illustrated by Mr Lister in a memoir read to the Royal Society on January 21, 1830, *On some Properties in Achromatic Object glasses, applicable to the Improvement of the Microscope*, and it was by working on the lines there laid down that the three London opticians Ross,[3] Powell, and James Smith soon produced microscopic objectives that surpassed any then constructed on the Continent, while the subsequent adoption of the same principles by French and German opticians, as also by Professor Amici of Florence, soon raised their objectives to a corresponding level

---

[1] It is due to Mr Joseph J Lister to mention that Tulley's final success with this low power seems to have been attained by working on a suggestion given him by that gentleman. See *Monthly Microscopical Journal*, vol. iii. (1870), p 134

[2] Thus he found that, while each of Chevalier's doublet combinations, when used singly, presented a "bur" or "coma" outwards, this coma, instead of being exaggerated by the combination of two of these doublets, was much diminished On the other hand, while two of Tulley's triplets, each of which performed admirably by itself, were used together, the images of all objects not in the centre presented a strong bur inwards with an under correction of colour

[3] In 1837 Mr Lister gave Mr Ross a projection for an objective of $\frac{1}{8}$ inch focus, in which a triple front was combined with two doublets The great superiority of this lens, admirably executed by Mr Ross, caused him to adopt its plan as the standard one for high powers, and it is still in general use,—the back lens also being sometimes made as a triplet.

It has proved more advantageous in practice to make the several components of an achromatic objective correct each others' aberrations than to attempt to render each perfect in itself, and the mode in which this is accomplished will vary with the focus and angular aperture given to each combination Thus, while a single "telescopic triplet" answers very well for the lowest power usually made (4 inches focus), and the same plan may be used—though at the sacrifice of angular aperture—for objectives of 3 inches, 2 inches, and even 1 inch focus, the best performance of these powers requires the combination of two doublets And, while this last system also serves for objectives of $\frac{2}{3}$ inch and $\frac{1}{2}$ inch of low angle, a third component is required for giving to these objectives the aperture that renders them most serviceable, as well as for all higher powers Instead of combining three achromatic doublets, however, many makers prefer placing in front a plano-convex of crown, and adding a third lens of crown to the doublet at the back, still using a doublet in the middle,—the whole combination thus consisting of six lenses, four of crown and two of flint Further, Mr Wenham has shown that the whole colour correction may be effected in the middle by interposing a double concave of dense flint between two double convex lenses of crown,—the back lens, as well as the front, being then a plano-convex of crown, making five lenses in all This plan of construction, though suitable to objectives of moderate angular aperture, and advantageous in regard to comparative simplicity and economy of construction, does not seem so well adapted for objectives to which the largest attainable aperture is to be given,—these being usually constructed with a triplet in front, a doublet in the middle, and a triplet at the back, so as to consist of eight separate lenses And the first-class constructors of achromatic objectives in the United States usually place in front of these, in their highest powers, a single plano-convex of crown, by the addition of which a greater working distance can be obtained But, as every such addition increases the liability to error from imperfections in the centring and grinding of the lenses (as well as loss of light by the partial reflexion of oblique rays from their surfaces), it is obvious that the most exact workmanship, involving a proportionate costliness, is required to bring out the full effect of such complex construction And where angular aperture is regarded as the quality of primary importance it will be usually found preferable to have recourse to objectives constructed on either the "water" or the "oil" immersion system, to be presently described.

The great increase thus attained in the perfection of the corrections of microscopic objectives for both spherical and chromatic aberration of course rendered it possible to make a corresponding increase in their angular aperture The minute scales of the wings of butterflies and other insects were naturally among the objects much examined, and it was soon perceived that certain lines and other markings became clearly discernible on these scales with objectives of what was then considered large angle which were utterly undistinguishable with non-achromatized microscopes (however high their magnifying power), and very imperfectly shown under achromatic objectives of small angle Hence these scales came to be used as "test-objects," for judging of the "definition" and "resolving power" of microscopic objectives,—the former property consisting in the clearness, sharpness, and freedom from false colour of the microscopic images of boundary lines, and depending on the accuracy with which the aberrations are corrected, while the latter term designates that power of separating very closely approximated markings which is now known to be a "function" of aperture The insect-scales formerly most valued for these purposes were those of the *Morpho menelaus* (fig 5) and the similarly lined scales of the *Polyommatus argus* (azure blue), the "battledoor" scales of the same butterfly (fig 6), the ribbed scales of the *Lepisma saccharina* (sugar louse), and the minute and peculiarly marked scales of the *Lepidocyrtus curvicollis* (fig 7), commonly known as the *Podura* The writer recollects the time when the satisfactory "resolution" of the first three of these tests was considered a sufficient proof of the goodness of even high power objectives, and when the *Podura* markings, if visible at all, could only be distinguished as striæ The further opening out of the aperture, however, enabled these striæ to be resolved into rows of "exclamation marks', and, while there is still some uncertainty as to the precise structure of which these markings are the optical expression, practical opticians are generally agreed that the *Podura* scale is very useful as a test for definition, with even the highest objectives, though it only serves as a test for a very moderate degree of resolving power For the latter purpose it has been completely superseded by the closely approximated markings of the silicified envelopes of certain diatoms (which, however, show themselves in very different aspects according to the conditions under which they are viewed, figs 8–11), and also by lines artificially ruled on glass, as in Nobert's "test plate,' the number of lines in the nineteen bands of which is stated by M Nobert to range from 1000 to 10,000 to a Paris line, while Dr Royston Pigott gives the numbers in an English inch as 11,529 to the inch in the first band, and 112,595 in the nineteenth This last dimension (as will afterwards appear) approaches the minimum distance at which such markings are theoretically separable by any magnifying power of the microscope

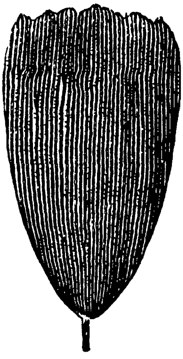


Fig 5 —Scale of *Morpho menelaus*

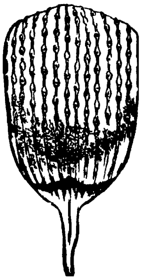


Fig 6 — Battledoor Scale of *Polyommatus argus*

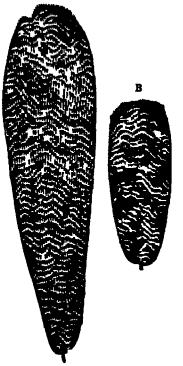


Fig 7 —Test Scales of Podura (*Lepidocyrtus curvicollis*) A, large strongly marked scale, B, small scale, more faintly marked

The enlargement of the angle of aperture of microscopic objectives and the greater completeness of their corrections, which were obtained in the first instance by the adoption of Mr Lister's principles, and were demonstrated by the resolution of the test-objects then in use, soon rendered sensible an imperfection in their performance under certain circumstances, which had previously passed unnoticed, and the important discovery was made by Mr Andrew Ross that a very decided difference exists in the precision of the image according as the object is viewed with or without a covering of thin glass, as also according as this cover is thin or thick.[1] As this difference increases in proportion to the widening of the aperture, it would obviously be a source of great error and embarrassment if a means could not be found for its rectification Its optical source, however, having been found by Mr Ross to lie in the "negative aberration" which is produced in the rays proceeding from the object to the front glass of the objective by the interposition of the plane glass cover, and which increases with its thickness, his practical ability enabled him at the same time to indicate the remedy, which consists in under correcting the front lens and over correcting the two posterior combinations, and in making the distance between the former and the latter capable of adjustment by means of a screw-collar, as shown in fig 12 For when the front pair is approximated most nearly to the next, and its distance from the object is increased, its excess of positive aberration is more strongly exerted upon the other two pairs than it is in the contrary conditions, and thus neutralizes the negative aberration produced by the interposition of the covering glass This correction is not needed for objectives of low or medium power and small angle of aperture, but it should always be provided when the angle exceeds 50°,—unless (as is now generally done in the case of objectives constructed for students' use) the maker adjusts them originally, not for uncovered objects, but for objects covered with glass of a standard thickness, say 0 005 or 0 004 inch A departure from that standard to the extent of one or two thousandths of an inch in either direction, though extremely injurious to the performance of objectives whose aperture is 125° or more, scarcely makes itself perceptible in those of 90° or 100° And the same may be said in regard to the immersion objectives next to be described, which are peculiarly suitable to the purposes of minute histological research

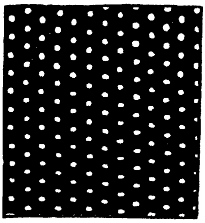


Fig 8.

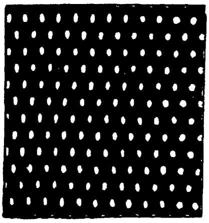


Fig 9

Fig 10

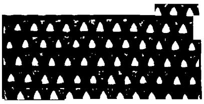


Fig 11

Portions of Siliceous Valve of *Pleurosigma angulatum* from a Photograph taken by Central Illumination Magnified 2000 diameters

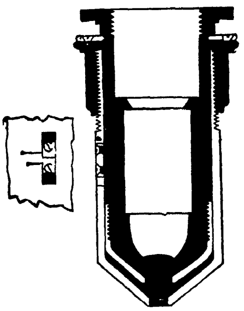


Fig 12 —Section of Adjusting Achromatic Object-Glass A uncovered, B, covered

Immersion System—It was long since pointed out by Professor Amici that the introduction of a drop of water between the front surface of the objective and either the object itself or its covering glass would diminish the loss of light resulting from the passage of the rays from the object or its covering glass into air, and from air into the front glass of the objective It was obvious to him, moreover, that when the rays enter the object-glass from water, instead of from air, both its refractive and its dispersive action will be so greatly changed as to need an important constructive modification to meet the new condition This modification seems never to have been successfully effected by Amici himself, but his idea was taken up by the two eminent Paris opticians, MM Hartnack and Nachet, who showed that the application of what is now known as the "immersion system to objectives of short focus and large angular aperture is attended, not merely with the advantages expected by Professor Amici, but with others on which he did not reckon As the loss of light by the reflexion of a portion of the incident rays increases with the obliquity of their incidence, and as the proportional loss is far smaller when the oblique rays pass into glass from water than when they enter it from air, the advantage of increasing the angular aperture is more fully experienced with "immersion" than with "dry' objectives,—just as Professor Amici anticipated But, further, the immersion system allows of a greater working distance between the objective and the object than can be attained with a dry or air objective having the same angular aperture, and this increase affords not only a greater freedom of manipulation, but also a greater range of "penetration" or "focal depth" Further, the observer is rendered so much less dependent upon the exactness of his cover correction that it is found that water immersion objectives of high power and considerable angular aperture, extremely well adapted for the ordinary purposes of scientific investigation, can be constructed without it,—a small departure from the standard thickness of covering glass to which such objectives are adjusted by the maker having scarcely any effect upon the distinctness of the image It is now the practice of several makers to supply two fronts to objectives of $\frac{1}{10}$ or $\frac{1}{12}$ inch focus, one of them fitting the objective for use "dry" (that is, in air), whilst the substitution of the other converts it into a water immersion objective And in the objectives constructed on Mr Wenham's system no change in the front glass is needed, all that is necessary for making them work as immersion lenses being a yet closer approximation of the front lens to the second combination, which can be made by the screw collar

Within the last few years, however, the immersion system has undergone a still further and most important development, by the adoption of a method originally suggested by Mr Wenham (though never carried out by him), and independently suggested by Mr Stephenson to Professor Abbe of Jena, under whose direction it was first worked out by Zeiss (the very able optician of Jena), who has been followed by Powell and Lealand of London, as well as by several other constructors of achromatic objectives both in England and elsewhere, with complete success This method consists in the replacement of the water previously interposed between the covering glass and the front glass of the objective by a liquid having the same refractive and dispersive powers as crown glass, so that the rays issuing at any angle from the upper plane surface of the covering glass shall enter the plane front of the objective, without any deflexion from their straight course, and without any sensible loss by reflexion,—even the most oblique rays that proceed from the object keeping their direction unchanged until they meet the back or convex surface of the front lens of the objective It is obvious that all the advantages derivable from the system of water immersion will be still more thoroughly attained by this system of "homogeneous" immersion, provided that a fluid can be obtained which meets its requirements After a long course of experiments, Professor Abbe found that oil of cedar wood so nearly corresponds with crown glass, alike in refractive and in dispersive power, as to serve the purpose extremely well, except when it is desired to take special advantage of the most divergent or marginal rays, oil of fennel being then preferable There are, however, strong objections to the use of these essential oils in the ordinary work of research, and it seems not unlikely that a solution of some one or more saline substances will be found more suitable In addition to the benefit conferred by the water immersion system, and more completely attained with the homogeneous, it may be specially pointed out that, as no correction for the thickness of the covering glass is here required, the microscopist can feel assured that he has such a view of his object as only the most perfect correction of an air objective can afford This is a matter of no small importance, for while, in looking at a known object, the practised microscopist can so adjust his air objective to the thickness of its covering glass as to bring out its best performance, he cannot be sure, in regard to an unknown object, what appearances it ought to present, and may be led by imperfect cover correction to an erroneous conception of its structure

---

[1] *Trans Soc of Arts*, vol. li.

It has been recently argued that as the slightest variation in the refractive index of either the immersion fluid or the covering glass a change of eye pieces or the least alteration in the length of the body—in a word any circumstances differing in the slightest degree from those under which the objective was corrected—must affect the performance of homogeneous immersion objectives of the highest class they should still be made adjustable The truth of this contention can no doubt be proved not only theoretically but practically —the introduction of the adjustment enabling an experienced manipulator to attain the highest degree of perfection in the exhibition of many mounted objects which cannot be so well shown with objectives in fixed settings But it may well be questioned whether it is likely to do the same service in the hands of an ordinary working histologist and whether the scientific investigator will not find it preferable when using these objectives to accept what their maker has fixed as their point of best performance The principal source of error in his employment of them lies in the thickness of the optical section of the object for the rays proceeding from its deeper plane having to pass through a medium intervening between that plane and the cover glass whose refractive and dispersive indices differ from those of the glass and immersion fluid, cannot be brought to so accurate a focus as those proceeding from the plane immediately beneath the cover glass The remedy for this however seems to lie rather in making the preparation as thin as possible than in the introduction of what is likely, in any but the most skilful and experienced hands to prove a new source of error Every one who has examined muscular fibre for example under a dry objective of very high power and large aperture, well knows that so great an alteration is produced in its aspect by the slightest change in either the focal adjustment or the cover correction that it is impossible to say with certainty what are the appearances which give the most correct optical expression of its structure This being a matter of judgment on the part of each observer it seems obvious that the nearest approach to a correct view will be probably given by the focal adjustment of the best homogeneous immersion objectives in fixed settings, to the plane of the preparation immediately beneath the cover glass (see *Jour Roy Micros Soc*, 1882, pp 407, 854, 906)

In every particular in which the water immersion system is superior to the dry, it is itself surpassed by the oil or other homogeneous system, the anticipations of those by whom it was suggested being thus fully realized But the advantages already spoken of as derivable from the use of the "immersion system" are altogether surpassed by that which the theoretical studies of Professor Abbe have led him to assign to it, and of which he has practically demonstrated its possession For he has shown (as will be explained below) that the interposition of either water or oil so greatly increases the real "aperture" of the objective that immersion objectives may be constructed having a far greater virtual aperture than even the theoretical maximum (180°) of the angular aperture of an air objective

The same eminent physicist, working on the basis supplied by the mathematical investigations of Professor Helmholtz and himself on the undulatory theory of light, has further established an entirely new doctrine in regard to the production of highly magnified representations of closely approximated markings All that has hitherto been said of the formation of images by the compound microscope relates to such as are produced, in accordance with the laws of refraction, by the alteration in direction which the light-rays undergo in their passage through the lenses interposed between the object and the eye These dioptric images, when formed by lenses free from spherical and chromatic aberration, are geometrically correct pictures, truly representing the appearances which the objects themselves would present were they enlarged to the same scale and viewed under similar illumination And we seem justified, therefore, in drawing from such microscopic images the same conclusions in regard to the objects they picture as we should draw from the direct vision of actual objects having the same dimensions The principal source of error in such interpretations arises out of the "interference" to which the rays of light are subjected along the edges of the minute objects through which they pass, or along any such lines or margins in their inner part as are sufficiently opaque to throw a definite shadow For every such shadow must be bordered, more or less obviously, by interference or *diffraction spectra*, and thus the images of strongly lined objects with very transparent intermediate spaces may be so troubled or confused by these "diffraction spectra" as to render it very doubtful what interpretation is to be put upon their appearances

A good example of this kind is afforded by the scales of the gnat or mosquito, which are composed of a very delicate double membrane strengthened by longitudinal ribs on both sides, those of the opposite sides uniting at the broad end of the scale, where they generally terminate as bristle shaped appendages beyond the intermediate membrane These are crossed by fine markings, which are probably ridge like corrugations of the membrane, common to both sides of the scale Between each pair of longitudinal ridges there may be seen under certain adjustments of focus and illumination three uniform parallel rows of beads, which have been supposed to represent a true structure in the membrane By Dr Woodward (colonel in the United States army), however, it has been shown that this beaded appearance is merely the result of the "interferences produced by the longitudinal and transverse lines of the scale For the longitudinal diffraction lines are clearly seen, alike in the microscopic image and in photographs (fig 13) to extend into empty space beyond the contour of the scales, almost as far as the ends of the bristles in which the parallel ribs terminate, and they vary in number with the varying obliquity of illumination, so that in the same scale two three four, or even five rows of beads can be seen, and photographed at pleasure, in every intercostal space [1]

Every microscopist who has worked much with high powers is well aware of the difficulty of distinguishing between real and spectral markings,—a difficulty which can only be overcome by training and experience It seems, however, to have been now fully ascertained by Professor Abbe that it is only through such diffraction spectra that the microscope can make us acquainted with the minutest structural features of objects, since, according to the calculations of Professor Helmholtz and himself (based on the constants of the undulatory theory), no amount of magnifying power can separate dioptrically two lines, apertures, or markings of any kind, not more than $\frac{1}{2500}$ of an inch apart The visual differentiation or "resolution" of lines or other markings whose distance lies within that limit is entirely the result of "interference,"—the objective receiving and transmitting, not only dioptric rays, but the inflected rays whose course has been altered in their passage through the object by the peculiar disposition of its particles, and combining these rays into a series of diffraction spectra, the number and relative position of which bear a relation to the structural arrangement on which their production depends If the objective be perfectly corrected, and all the diffraction spectra lie within its field, these will be recombined by the eye piece so as to form a secondary or "diffraction" image, lying in the same plane with the dioptric image, and coinciding with it, while filling up its outlines by supplying intermediate details But where the markings (of whatever nature) are so closely approximated as to produce a wide dispersion of the interference spectra, only a part of them may fall within the range of the objective, and the recombination of these by the eye piece may produce a diffraction image differing more or less completely (perhaps even totally) from the real structure, while, if they should lie entirely outside the field of the objective, no secondary or diffraction image will be produced And thus, while the general form of such an object as a diatom valve may be correctly given in a dioptric image, its surface may appear quite unmarked under an objective of small aperture, however great its magnifying power, though covered with regularly disposed markings when seen through an objective of wider aperture with perhaps only half the magnifying power

---

[1] *Monthly Micros Jour*, vol v (1876), p 253

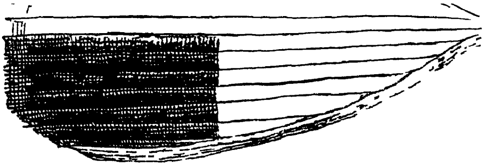


FIG 13 —Scale of Gnat showing Beaded Markings produced by Diffraction, from a Photograph by Colonel Dr Woodward

It is obvious, however, that, while the dioptric image represents the actual object, the diffraction image thus formed by the reunion of a portion of the interference pencils is only an optical expression of the result of their partial recombination, which may represent something entirely different from the real structure For it has been proved experimentally, by placing finely ruled gratings in the position of objects, and by limiting the apertures of objectives by diaphragms with variously disposed perforations, that the same arrangement of lines shall be presented to the eye by differently lined surfaces, and different arrangements by similarly lined surfaces, according to the numbers and relative positions of the reunited spectra Hence it is clear that there must be an essential difference in character and trustworthiness between the images dioptrically formed of the general outlines and larger details of microscopic objects and those representations of their finer details which are given by the recombination of their diffraction spectra,[1] and that the confidence to be placed in the latter class of representations will be greater in proportion to the completeness of the recombination of the separated interference spectra, which, again, will be proportional (accurate correction of the aberrations being assumed) to the aperture of the objective [2]

The combined advance of scientific theory and of practical skill in the application of it have now brought up the compound achromatic microscope to an optical perfection that renders it capable of actually doing almost everything of which, in the present state of optical theory, it can be regarded as capable The resolution of Nobert's nineteenth band, having 112,595 lines to an inch, which was long regarded as the *crux* of microscopists, is now found so easy as to leave little room for doubt that, if a new test were obtainable having the *minimum visibile* of 118,000 lines to the inch, an oil immersion objective would be found to resolve it But the experience of the past makes it evident that, as no limit can be set to the advance of optical theory, results yet more remarkable may be still expected to arise, every such advance being turned to account by the practical skill which experience has now enabled the best constructors of achromatic objectives to attain [3]

The progressive improvements thus effected in the construction of microscopic objectives have been accompanied by other improvements, alike in the optical and in the mechanical arrangements by which the best performance of these objectives can be secured and it will be desirable now to describe in succession the most approved forms of the eye piece the objective, and the illuminating apparatus respectively, and then those of the instrument as a whole, pointing out the special adaptiveness of each to the requirements of different classes of scientific investigators

Eye Pieces

It very early became obvious to those who were engaged in the achromatization of microscopic objectives that their best performance was obtained when the image given by them was further enlarged by the eye piece known as the Huygenian, as having been devised by Huygens for his telescopes It consists of two plano convex lenses (EE and FF, fig 4), with their plane sides towards the eye these are placed at a distance equal to half the sum of their focal lengths —or to speak with more precision, at half the sum of the focal length of the eye glass, and of the distance from the field glass at which an image of the object glass would be formed by it A ' stop or diaphragm BB must be placed between the two lenses, in the visual focus of the eye glass, which is, of course, the position wherein the image of the object will be formed by the rays brought into convergence by their passage through the field glass Huygens devised this arrangement merely to diminish the spherical aberration, but it was subsequently shown by Boscovich that the chromatic dispersion was also in great part corrected by it Since the introduction of achromatic object glasses for compound microscopes, it has been further shown that nearly all error may be avoided by a slight over correction of these, so that the blue and red rays may be caused to enter the eye in a parallel direction (though not actually coincident), and thus to produce a colourless image Thus let N, M N (fig 14) represent the two extreme rays of three pencils, which without the field glass would form a blue image convex to the eye glass at BB, and a red one at RR, then, by the intervention of the field glass, a blue image concave to the eye glass is formed at B B, and a red one at R′R′ As the focus of the eye glass is shorter for blue rays than for red rays by just the difference in the place of these images, their rays, after refraction by it, enter the eye in a parallel direction, and produce a picture free from false colour If the object glass had been rendered perfectly achromatic, the blue rays, after passing through the field glass, would have been brought to a focus at *b*, and the red at *r*, so that an error would be produced which would have been increased instead of being corrected by the eye glass Another advantage of a well constructed Huygenian eye piece is that the image produced by the meeting of the rays after passing through the field glass is by it rendered concave towards the eye glass instead of convex, so that every part of it may be in focus at the same time, and the field of view thereby rendered flat[1]

---

[1] Thus it is still a moot point whether the microscopic appearances seen in the siliceous valves of diatoms (figs 8–11) are the optical representations of elevations depressions, or perforations, or of internal molecular arrangements not involving any inequality of surface

[2] This doctrine was first fully developed by Professor Abbe in the *Archiv fur Microsk Anatomie*, vol ix (1874), and is more fully expounded in his subsequent contributions to *Jour R y Micros Soc* See also the papers of Mr Stephenson and Mr Crisp in that journal, and in the preceding *Monthly Microscopical Journal*

[3] Any good workman can now make by the dozen such small angled $\frac{1}{4}$ inch objectives as Mr A Ross produced with much pains and labour fifty years ago It was not until 1844 that, with the honourable emulation of surpassing what Professor Amici had then accomplished, he produced a $\frac{1}{12}$ inch of 135°, which, by taking advantage of some very heavy flint glass he had, he afterwards increased to 170°.

[illegible]

a compound microscope The utility of the higher powers will mainly depend upon the excellence of the objectives for when an achromatic combination of small aperture which is sufficiently well corrected to perform very tolerably with a ‘ low or ‘ shallow eye piece is used with an eye piece of higher magnifying power (commonly spoken of as a ‘ deeper one) the image may lose more in brightness and in definition than is gained by its amplification, while the image given by an objective of large angular aperture and very perfect correction shall sustain so little loss of light or of definition by ‘ deep eye piecing that the increase of magnifying power shall be almost clear gain Hence the modes in which different objectives of the same power, whose performance with shallow eye pieces is nearly the same, are respectively affected by deep eye pieces afford a good test of their respective merits since any defect in the corrections is sure to be brought out by the higher amplification of the image, while a deficiency of aperture is manifested by the want of light The working microscopist will generally find the A eye piece most suitable B being occasionally employed when a greater power is required to separate details whilst C and others still deeper are useful for the purpose of testing the goodness of objectives, or for special investigations requiring the highest amplification with objectives of the finest quality But he can commit no greater error than habitually to use deep eye pieces for the purposes of scientific research especially when (as in the study of living objects) long continued and unintermitted observation is necessary For the visual strain thus occasioned is exactly like that resulting from the habitual use of magnifying spectacles in reading, requiring the book to be held within 2 or 3 inches of the eye And all experience shows that this feeling of strain cannot be disregarded, without the most injurious consequences to vision

For viewing large flat objects such as transverse sections of wood or of *Echinus* spines, under low magnifying powers, the eye piece known as Kellner s may be employed with advantage In this construction the field glass, which is a double convex lens, is placed in the focus of the eye glass without the interposition of a diaphragm, and the eye glass is an achromatic combination of a plano concave of flint with a double convex of crown, which is slightly under corrected, so as to neutralize the over correction given to the objectives for use with Huygenian eye pieces A flat well illuminated field of as much as 14 inches in diameter may thus be obtained with very little loss of light, but, on the other hand, there is a certain impairment of defining power which renders the Kellner eye piece unsuitable for objects presenting minute structural details, and it is an additional objection that the smallest speck or smear upon the surface of the field glass is made so unpleasantly obvious that the most careful cleansing of that surface is required every time that this eye piece is used Hence it is better fitted for the occasional display of objects of the character already specified than for the ordinary wants of the working microscopist

Solid eye pieces, consisting of cylinders of glass with convex ends, are sometimes used in place of the Huygenian, when high magnifying power is required for testing the performance of objectives The lower surface, which has the lesser convexity, serves as a field glass while the image formed by this is magnified by the highly convex upper surface to which the eye is applied,—the advantage derivable from this construction lying in the abolition of the plane surfaces of the two lenses of the ordinary eye piece[2]

A “ positive or Ramsden s eye piece—in which the field glass, whose convex side is turned upwards, is placed so much nearer the eye glass that the image formed by the objective lies below instead of above it—was formerly used for the purpose of micrometry,—a divided glass being fitted in the exact plane occupied by the image, so that its scale and that image are both magnified together by the lenses interposed between them and the eye The same end, however, may be so readily attained with the Huygenian eye piece that no essential advantage is gained by the use of that of Ramsden, the field of which is distinct only in its centre

OBJECTIVES

It has been seen that one of the principal points in the construction of microscopic objectives to which the attention of their makers has been constantly directed has been the enlargement of their “ aperture, —this term being understood to mean not their absolute opening as expressed by linear measure, but their

[illegible]

aperture, —that is, by the degree of divergence of the most extreme rays proceeding from the axial point of the object to the margin of the objective (fig 15) which take part in the formation of the image It is pointed out, however, by Professor Abbe that, in the case of single lenses used as objectives, their apertures are really proportional, not to their respective angles of aperture, but to the ratio between the actual diameter or clear opening of each to its focal distance, a ratio which is simply expressed by the sine of its semiangle And in the case of combinations of lenses it can be demonstrated mathematically that their respective apertures are determinable—other conditions being the same—by the ratio of the diameters of their back lenses, so far as these are really utilized, to their respective focal lengths,—this ratio being expressed as before, by the sine of the semiangle of aperture (sin *u*) The difference between these two modes of comparison can be readily made obvious by reference to the theoretical maximum of

FIG 15 —Section of Achromatic Object Glass, composed of three pairs of (flint and crown) lenses *abc* is its angle of aperture

[illegible]

having an angle of 60° would count by comparison of angles as having only one third of the theoretical maximum, its real aperture would be half that maximum since the sine of its semiangle (30°) = $\frac{1}{2}$ And, as the sines of angles beyond 60° increase very slowly, an objective of 120° angle will have as much as 87 per cent of the theoretical maximum of aperture, although its angle is only two thirds, or 66 6 per cent, of 180° It hence becomes obvious that little is really gained in real aperture by the opening out of the angle of microscopic objectives to its greatest practicable limit (which may be taken as 170°), while such extension—even if unattended with any loss either of definition or of colour correction—necessarily involves a great reduction alike in the working distance and in the focal depth or penetration of the combination, as will be presently explained

Numerical Aperture —It has now been demonstrated by Professor Abbe that, independently of the advantages already specified as derivable from the application of the immersion system to objectives of short focus and wide aperture, the real aperture of an immersion objective is considerably greater than that of a dry or air objective of the same angle,—the comparative apertures of objectives working through different media being in the compound ratio of two factors, viz, the sines of their respective semiangles of aperture and the refractive indices of the “ immersion fluids It is the product of these ($n \sin u$) that gives what is termed by Professor Abbe the ‘ numerical aperture, ’—which serves therefore, as the only true standard of comparison, not only between dry or air and water or oil immersion lenses, but also between immersion lenses adapted to work respectively with water, oil, or any other interposed fluid That the angle of aperture expressed by the same number of degrees must correspond with very different working apertures in dry, water immersion, and oil or homogeneous immersion objectives becomes evident when we consider what happens when divergent pencils of rays pass from one medium into another of higher refractive index. For such divergent pencils, proceeding from air into water or oil, will be closed together or compressed; so that the rays which, when an object is mounted in air spread out over the whole hemisphere then form comparatively narrow pencils, and can thus be utilized by an immersion objective of smaller aperture than is required in a dry objective to admit the most diverging rays of air pencils. It follows, therefore, that a given angle in a water or oil immersion objective represents a much larger aperture than does the same angle in an air objective; and thus it comes to pass that by opening out the angle of immersion objectives they may be made to receive and utilize rays of much greater divergence than can possibly enter dry objectives of even maximum aperture.

---

[1] The reader may be referred to Mr Varley s investigation of the properties of the Huygenian eye piece in the fifty first volume of the *Transactions of the Society of Arts* and to the article ‘ Microscope by Mr Ross in the *Penny Cyclopædia* reprinted, with additions, in the *English Cyclopædia*

[2] These eye pieces are much in vogue in the United States, where they are made of extremely short foci,—even to $\frac{1}{16}$ inch

The following table, abridged from that given by Professor Abbe for every 0·02 of numerical aperture from 0·50 up to the maximum of 1·52, brings this contrast into clear view:—

Numerical Aperture Table.

Numerical Aperture ($n \sin u = a$)	Angle of Aperture (=$2u$)			Illuminating Power (a^2)	Theoretical Resolving Power in Lines to an Inch (λ=0·5269 μ =line F)	Penetrating Power $\left(\frac{1}{a}\right)$
	Dry Objectives (n=1)	Water Immersion Objectives (n=1·33)	Homogeneous Immersion Objectives (n=1·52)			
	°	°	°			
1·52			180 0	2·310	146,528	·658
1·42			138 12	2·016	136,888	·704
1·33		180 0	122 6	1·770	128,212	·752
1·26		142 39	111 59	1·588	121,464	·794
1·18		125 3	101 50	1·392	113,752	·847
1·12		114 44	94 56	1·254	107,968	·893
1·06		105 42	88 26	1·124	102,184	·943
1·00	180 0	97 31	82 17	1·000	96,400	1·000
0·94	140 6	89 56	76 24	·884	90,616	1·064
0·86	118 38	80 34	68 54	·740	82,904	1·163
0·80	106 16	73 58	63 31	·640	77,120	1·250
0·76	98 56	69 42	60 0	·578	73,264	1·316
0·70	88 51	63 31	54 50	·490	67,480	1·429
0·62	76 38	55 34	48 9	·384	59,768	1·613
0·56	68 6	49 48	43 14	·314	53,984	1·786
0·50	60 0	44 10	38 24	·250	48,200	2·000

Thus, taking as a standard of comparison a dry objective of the maximum theoretical angle of 180°, whose numerical aperture is the sine of 90°, or 1·00, we find this standard equalled by a water immersion objective whose angle of aperture is no more than 97½°, and by an oil or homogeneous immersion objective of only 82°,—the numerical apertures of these, obtained by multiplying the sines of their respective semiangles by the refractive index of water or of oil, being 1·00 in each case. Each, therefore, will have as great a power of receiving and utilizing divergent rays as any dry objective can even theoretically possess.

But, as the actual angle of either a water or an oil immersion objective can be opened out to the same extent as that of an air or dry objective, it follows that the aperture of the former can be augmented far beyond even the theoretical maximum of the latter. Thus the numerical aperture of a water immersion lens of the maximum angle of 180° is 1·33, or one third greater than that of an air lens of the same angle; and this aperture would be given by an oil immersion objective of only 122°. Again, the numerical aperture of an oil immersion objective having the theoretical maximum angle of 180° would be 1·52, or more than one half greater than that of an air lens of the same angle. And the numerical apertures corresponding to angles of 170° which have been actually attained in both cases, fall very little short of the proportions just given.

So, again, an oil immersion objective whose angle of aperture is only 60° has as high a numerical aperture (0·76) as a water immersion objective of 69½°, or as a dry objective of 99°; and a dry objective of 140° has no greater a numerical aperture (0·94) than a water immersion of 90° or an oil immersion of 76½°.

This important doctrine may be best made practically intelligible by a comparison of the relative diameters of the back lenses of dry with those of water and oil immersion objectives of the same power, from an "air angle" of 60° to an "oil angle" of 180°,—these diameters expressing, in each case, the opening between the extreme pencil forming rays at their issue from the posterior surface of the combination to meet in its conjugate focus for the formation of the image; the relation of which opening in each case to the focal length of the combination is the real measure of its aperture (fig. 16). Thus the dry objective of 60° angle (5 in fig. 16) has its air angle represented by $\sin u = \frac{1}{2} = 0{\cdot}50$ numerical aperture. The dry objective of 97° (4) has its air angle represented by $\sin u = \frac{3}{4} = 0{\cdot}75$ numerical aperture. And the dry objective having the (theoretical) angle of 180° (3) has its air angle represented by $\sin u = 1{\cdot}00$ numerical aperture,—this corresponding to 96° water angle and 82° oil angle. But the water immersion lens having the (theoretical) angle of 180° (2) has its water angle represented by $n \sin u = 1{\cdot}33$ numerical aperture. And the oil immersion lens having the (theoretical) angle of 180° (1) has its oil angle represented by $n \sin u = 1{\cdot}52$ "numerical aperture."[1] These theoretical apertures for water and oil immersion lenses having been found as nearly attainable in practice as the theoretical maximum for dry objectives, such lenses can utilize rays from objects mounted in balsam or other dense media, which are entirely lost for the image (since they do not exist physically) when the same object is in air or is observed through a film of air. And this loss cannot be compensated by an increase of illumination, because the rays which are lost are different rays physically from those obtained by any illumination, however intense, through an aeriform medium.

It is by increasing the number of diffraction spectra that the additional rays thus received by objectives of great numerical aperture impart to them an increased resolving power for lined and dotted objects,—the truth of the image formed by the recombination of these spectra being (as already shown) essentially dependent on the number of them that the objective may be capable of receiving.

But whilst the resolving power of microscopic objectives increases in the ratio of their respective numerical apertures, and whilst their illuminating power (dependent upon the quantity of light that passes through them) increases with the square of the numerical aperture, the case is reversed with another most important quality,—that of penetration or focal depth, for this diminishes as the numerical aperture increases, until nothing but what is precisely in the focal plane can be even discerned with objectives possessed of the highest resolving power. Thus, the penetrating power of an objective of 60° air angle being expressed as 2·000, an extension of that angle to 76½° reduces it to 1·613, an extension to 89° reduces it to 1·429, and an extension to 99° reduces it to 1·316, further extension to 118½° reduces it to 1·163, while an objective whose air angle is 140° has a penetrating power of only 1·064. So, again, the oil immersion objective which has the numerical aperture of 1·00 corresponding to the theoretical air angle of 180° has a penetrating power of 1·000; this is brought down to ·752 when its angle is so increased as to make its numerical aperture 1·33, equalling the theoretical maximum of a water immersion objective, and is ·658 at the theoretical maximum (1·52) of an oil objective.

[redacted]

Fig. 16.—Relative [illegible]meters of Back Lenses of Air, Water, and Oil Immersion Objectives.

The dotted circles in the interior of 1 and 2 of the same diameter as 3, show the excess in the diameters of the back lenses of the water and oil objectives over that of the dry at their respective theoretical limits.

Hence it is clear that as some of the qualities to be sought in microscopic objectives are absolutely incompatible, a preference is to be accorded to objectives of greatest resolving power but very little penetration, or to those of moderate resolving power and great penetration according to the uses to which they are to be applied, and some general principles will now be laid down in regard to this matter, based alike on science and experience.

In the first place a marked distinction is to be drawn between those objectives of low or moderate power which are to be worked dioptrically and those of high power which are to be worked diffractively. The objects on which the former are to be for the most part used are either minute transparent bodies having solid forms which the observer should be able to take in as wholes (as in the case of *Polycystina*, the larger diatoms, *Infusoria*, &c.), or transparent sections, dissections, or injections, whose parts lie in different planes, the general relations of which he desires to study, while reserving their details for more special scrutiny; or opaque objects, whose structure can only be apprehended from the examination of their surfaces, when the inequalities of those surfaces are seen in their relations to each other. In all these cases it is desirable that microscopic vision should resemble ordinary vision as much as possible. If the eye were so constructed as to enable us to discern only those parts of an object that lie precisely in the plane to which we focus it, our visual conceptions of the forms and relations of these parts, and consequently of the object as a whole, would in general be very inadequate, and often erroneous. It is because, while focussing our eye successively on the several planes of the object, we can see the relation of each to what is nearer and more remote that we can readily acquire a visual conception of its shape as a whole, and that unmistakable perception of solid form which is given by the combination of the two dissimilar perspectives of near objects in binocular vision.

(p. 273) could not possibly be formed if our vision were strictly limited to the exact plane for which our eyes are focussed.

Hence it is obvious that, in the case of objectives of low and moderate amplification, focal depth or penetration is a quality for the want of which no other excellence can compensate,—the opening out of their apertures being only advantageous in so far as it does not seriously interfere with their penetrating power. It is, no doubt, quite possible to construct a 1 inch objective with an aperture so large that, when the requisite amplification has been gained by deep eye-piecing, it shall resolve the lined "tests" ordinarily used for a ¼; or to construct an objective of $\frac{4}{10}$ inch focus which shall in like manner do the ordinary work of a ⅛. But, as such objectives are thereby spoiled for their own proper work, the loss to the microscopist is but poorly compensated by his ability to resolve with them under such deep eye pieces as cannot be habitually used without serious risk to the eye sight the lined and dotted tests which can be much better shown under objectives of shorter focus and wider aperture with eye pieces of low amplification. For, whilst deep eye pieces cannot be habitually employed for continuous observation, without putting a strain upon the eyes resembling that which results from the constant use of a magnifying glass, even the very highest objectives may be used continuously for long periods in combination with shallow eye pieces with scarcely any fatigue and therefore (it is probable) without sensible injury.[1]

In estimating the goodness of a microscopic objective five distinct qualities have to be separately considered:—(1) its working distance, or the actual interval between its front lens and the object on which it is focussed; (2) its penetrating power or focal depth; (3) the flatness of its field; (4) its definition, or power of giving a distinct image of all well marked features of an object and especially of their boundary lines; and (5) its resolving power, by which it separates closely approximated lines, dots or striæ.

1. The "working distance" of an objective has no fixed relation to its focal length,—the latter being estimated by its equality in power with a single lens of given radius of curvature (such as 1 inch, ¼ inch, $\frac{1}{12}$ inch, &c.), while the former varies with the mode in which the combination is constructed and with the aperture given to it. For low and moderate powers, ranging up to $\frac{4}{10}$ inch focus, good working distance is especially important, alike because it is closely related to penetrating power and also because it facilitates the use of side illumination for opaque objects. And in such objectives of high power as are to be used, not for the resolution of lined or dotted tests, but for the observation of living and moving objects of extreme minuteness, good working distance is no less important on account of its relation to focal depth. In the case of those objectives, on the other hand, in which resolving power is made the first consideration, it is only needful that the working distance shall be such as to permit the interposition of a thin glass cover; and this, although necessarily diminished with the widening of the aperture, can be always obtained by the adoption of the immersion system.

2. The "penetrating power" or "focal depth" of an objective may be defined as consisting in the vertical range through which the parts of an object not precisely in the focal plane may be seen with sufficient distinctness to enable their relations with what lies exactly in that plane to be clearly traced out,—just as would be done by ordinary vision if the object were itself enlarged to the dimensions of its microscopic image. The close relation between this quality and the preceding becomes obvious when it is considered that the longer the working distance of an objective the less will the distinctness of the image it forms be affected by any given alteration (say the $\frac{1}{10000}$ of an inch) in its focal adjustment. Consequently, of two objectives having the same magnifying power but different working distances that one will have the most focal depth whose working distance is the greater. On the other hand, as the penetrating power of an objective is reduced in direct accordance with the increase of its numerical aperture, it must be sacrificed wherever the highest resolving power is to be attained. Hence, as already remarked, this attribute will be very differently valued by different observers according to the work on which they are respectively engaged. For the general purposes of biological research, not only with low or moderate (for the reasons already stated), but also with high powers, a considerable amount of focal depth is essential. It is impossible, for example, to follow satisfactorily the movements of an *Amœba*, or to study the "cyclosis" in the cell of a *Vallisneria*, or to trace the distribution of a nerve thread, with an objective in which focal depth is so completely sacrificed to aperture that nothing can be discerned save what is precisely in the focal plane, since, instead of passing gradationally from one focal plane to another, as the observer can do with an objective of good penetration, he can only get a succession of "dissolving views," with an interval of "chaos" between each pair. When, on the other hand, it is desired to scrutinize with the greatest precision such minute details as are presented in one and the same focal plane (as, for example, those of the thinnest possible film of tissue spread out between a glass slide and its covering glass), the microscopist will prefer an objective in which focal depth is subordinated to aperture, for the sake of the resolving power which he can thus command. And it will often happen in biological research that it is advantageous thus to bring objectives of the latter class to bear upon objects which could not have been detected in the first instance save by objectives of much inferior resolving power but greater focal depth.

3. The "flatness of the field" afforded by the objective is a condition of great importance to the advantageous use of the microscope, since the extent of the area clearly seen at one time practically depends upon it. Many objectives are so constructed that, even when the object is perfectly flat, the foci of the central and peripheral parts of the field are so different that, when the adjustment is made for one, the other is more or less indistinct. Hence, when the central part of the area is in focus, no more information is gained respecting the peripheral than if the latter had been altogether stopped out. With a really good objective not only should the image be distinct over the whole field at once, but the marginal portion should be as free from colour as the central. As imperfection in this respect is often masked by the contraction of the aperture of the diaphragm in the eye piece, the relative merits of two objectives as regards flatness of field should always be tested under an eye piece giving a large aperture.

4. The "defining power" of an objective, which depends upon the completeness of its corrections for spherical and for chromatic aberration and upon the accurate centring of its component lenses, is an attribute essential to its satisfactory performance, whatever may be its other qualities,—its importance in scientific research being such that no superiority in resolving power can compensate for the want of it; and, though it is possible to obtain perfect correction for spherical aberration up to the highest practicable limit of angle, yet the difficulty of securing it increases rapidly with the augmentation of aperture, the want of it being made perceptible, especially when deep eye pieces are put on, by the blurring of clearly marked lines or edges and by general fog. Perfect colour correction, on the other hand, is not possible for dry lenses of the widest angle, on account of the irrationality of the secondary spectrum; but this may be neutralized by the use of the immersion system. As already stated, what has to be aimed at in the construction of microscopic objectives is not absolute colour correction, but a slight degree of over correction, which, by compensating the chromatic dispersion of the Huygenian eye piece, shall produce an image free from false colour. As this can be secured far more easily in the construction of objectives of moderate than in those of very wide aperture, the cost of the former is proportionally small,—an additional reason for the preference to be given to them on other grounds, in regard to all save very special kinds of microscopic work.

5. "Resolving power," being that by which very minute and closely approximated markings—whether lines, striæ, dots or apertures—can be separately discerned, is a function which is only of primary importance in objectives whose amplifying power specially fits them for the study of objects of this class. It appears from the mathematical researches of Professor Abbe that the maximum resolving power (with a theoretical angle of 180°) would be capable of separating 146,528 lines to the inch; but he considers the limit of visual resolution depending on the power of the eye to be about $\frac{1}{118000}$ of an inch; and this limit seems to have been nearly reached. To make such a separation distinctly perceptible, an amplification of at least 3000 linear would be requisite; and this can only be obtained either by the use of an objective of very high power (such as $\frac{1}{25}$ inch focus) in combination with a low or medium eye piece, or by putting a very deep eye piece upon an objective of lower power (such as a ¼ inch),—the former method, for the reasons already given, being decidedly preferable. For the resolution of less closely approximated markings objectives of $\frac{1}{20}$, $\frac{1}{16}$, $\frac{1}{12}$, and ⅛ inch answer very well; and the resolving power which they require may be obtained without any excessive widening of the aperture. For the loss of resolving power consequent upon the contraction of the angle of a water immersion objective to 128⅓° is only one tenth of the theoretical maximum 128,212; while a reduction to 105⅔° only lowers the number of separable lines to 102,184 to the inch,—thus diminishing the resolving power by little more than one fifth, while the working distance and focal depth of the combination are greatly increased, and perfect definition is more certainly attainable. The ⅛ inch is (according to the writer's experience, which is confirmed by the theoretical deductions of Professor Abbe) the lowest objective in which resolving power should be made the primary qualification,—the ⅙, ⅕, ¼ and $\frac{4}{10}$ inch being specially suited to kinds of biological work in which this is far less important than focal depth and dioptric precision. This view is strengthened by the very important consideration that the resolving power given by wide aperture cannot be utilized, except by a method of illumination that causes light to pass through

---

[1] Hence for work of this kind the shallower eye pieces and longer tubes of English microscopes are to be preferred to the deeper eye pieces and shorter tubes of the ordinary Continental model, the shallowest eye pieces of the latter being usually equal in power to the ordinary B eye pieces of the former.

the object at an obliquity corresponding to that at which the most divergent rays enter the objective Now, although in the case of objects whose markings are only superficial such obliquity may not be productive of false appearances (though even this is scarcely conceivable), it must have that effect when the object is thick enough to have an internal structure, and the experience of all biological observers who have carried out the most delicate and difficult investigations is in accord, not only as to the advantage of direct illumination, but as to the deceptiveness of the appearances given by oblique, and the consequent danger of error in any inferences drawn from the latter Thus for example, the admirable researches of Strassburger Fleming Klein and others upon the changes which take place in cell nuclei during their subdivision can only be followed and verified (as the writer can personally testify) by examination of these objects under axial illumination with objectives of an angle so moderate as to possess focal depth enough to follow the wonderful differentiation of component parts brought out by staining processes through their whole thickness

The most perfect objectives for the ordinary purposes of scientific research therefore, will be obviously those which combine exact definition and flatness of field with the widest aperture that can be given without an inconvenient reduction of working distance and loss of the degree of focal depth suitable to the work on which they are respectively to be employed These last attributes are especially needed in the study of living and moving objects and, in the case of these dry objectives are decidedly preferable to immersion, since the shifting of the slide which is requisite to enable the movement of the object to be followed is very apt to produce disarrangement of the interposed drop And owing to the solvent power which the essential oils employed for homogeneous immersion have for the ordinary cements and varnishes, such care is necessary in the use of objectives constructed to work with them as can only be given when the observer desires to make a very minute and critical examination of a securely mounted object

The following table expresses the magnifying powers of objectives constructed on the English scale of inches and parts of an inch, with the 10 inch body and the A and B eye pieces usually supplied by English makers, and also specifies the angle of aperture which, in the writer s judgment is most suitable for each He has the satisfaction of finding that his opinions on this latter point, which are based on long experience in the microscopic study of a wider range of animal and vegetable objects than has fallen within the purview of most of his contemporaries are in accordance with the conclusions drawn by Professor Abbe from his profound investigations into the theory of microscopic vision [1] which have been carried into practical accomplishment in the excellent productions of Mr Zeiss

Focal Length	Angular Aperture	Magnifying Power		Focal Length	Angular Aperture	Magnifying Power	
		A Eye piece	B Eye piece			A Eye piece	B Eye piece
	°				°		
4 inches	9	12	18	$\frac{1}{4}$ inch	50–80	200	300
3	12	18	27	$\frac{1}{5}$	95	250	375
2	15	25	37	$\frac{1}{6}$	110	300	450
$1\frac{1}{2}$	20	36	54	$\frac{1}{8}$	140	400	600
1	30	50	75	$\frac{1}{10}$	150	500	750
$\frac{2}{3}$	40	75	112	$\frac{1}{12}$	160	600	900
$\frac{1}{2}$	45	100	150	$\frac{1}{16}$	170	800	1200
$\frac{4}{10}$	70	125	187				

For ordinary biological work the $\frac{1}{8}$ $\frac{1}{10}$ and $\frac{1}{12}$ objectives with angles of from 100° to 120° will be found to answer extremely well if constructed on the water immersion system

Each of these powers should be tested upon objects most suited to determine its capacity for the particular kind of work on which it is to be employed and in such testing the application of deeper eyepieces than can be habitually employed with advantage will often serve to bring out marked differences between two objectives which seem to work almost equally well under those ordinarily used — defects in definition or colour correction and want of light which might otherwise have escaped notice being thus made apparent No single object is of such general utility for these purposes as a large well marked *Podura* scale for the eye which has been trained to the use of a particular specimen of it will soon learn to recognize by its means the qualities of any objective between 1 inch and $\frac{1}{8}$ inch focus and it may be safely asserted that the objective which most clearly and sharply exhibits its characteristic markings is the best for the ordinary work of the histologist

For the special attribute of resolving power on the other hand, tests of an entirely different order are required and these are furnished, as already stated either by the more difficult diatoms, or by the highest numbers of Nobert s ruled test plate The diatom valve at present most in use as a test for resolving power is the *Amphipleura pellucida* the lines on which were long supposed to be more closely approximated than those of Nobert s nineteenth band, being affirmed by Mr Sollitt to range from 120 to 130 in $\frac{1}{1000}$ of an inch But the admirable photographs of this valve obtained by Colonel Dr Woodward have confirmed the conclusion long previously expressed by the writer, that this estimate was far too high, being based on the "spurious lineation" produced by diffraction, and show that the striæ on the largest valves do not exceed 91, while those on the smallest are never more numerous than 100, in $\frac{1}{1000}$ of an inch The same admirable manipulator has also obtained excellent photographs of another very difficult test diatom, *Surirella gemma*, from which it appears that its transverse striæ count longitudinally at the rate of 72,000 to the inch, whilst the beaded appearances into which these may be resolved count transversely at the rate of 84,000 to the inch. Thus it appears that the complete resolution of these "vexatious" diatoms does not require by any means the maximum of aperture, but is probably dependent at least as much on the perfection of the corrections and the effectiveness of the illumination

It must be understood that there is no intention in these remarks to undervalue the efforts which have been perseveringly made by the ablest constructors of microscopic objectives in the direction of enlargement of aperture For these efforts besides increasing the resolving power of the instrument have done the great service of producing a vast improvement in the quality of those objectives of moderate aperture which are most valuable to the scientific biologist and the microscopist who wishes his *armamentum* to be complete will provide himself with objectives of those different qualities, as well as different powers, which shall best suit his particular requirements [2]

ILLUMINATING APPARATUS

Every improvement in the optical performance of the compound achromatic microscope has called forth a corresponding improvement in the illumination of the objects viewed by it, since it soon came to be apparent that without such improvement the full advantage of the increased defining and resolving powers of the objectives could not be obtained For the illumination of transparent objects examined by light transmitted through them under low powers of moderate angle a converging pencil of rays reflected upon their under surface by a concave mirror is generally sufficient,— a ' condenser being only needed when the imperfect transparency of the object requires the transmission of more light through it And the microscopist engaged in ordinary biological studies, who works on very transparent objects with objectives of $\frac{1}{4}$ or $\frac{1}{8}$ inch focus or $\frac{1}{12}$ inch immersion will find that the small concave mirror of short focus with which the Continental models are furnished (see fig 28) will generally prove sufficient for his needs This mirror is usually hung at such a distance beneath the stage that parallel rays falling on it are brought to a focus in the object as it lies on a slip of glass resting on the stage and thus when the instrument is used by day, the light of a bright cloud (which is preferable to any other) gives a well illuminated field, even with the powers last mentioned But when lamp light is used its divergent rays are not brought to a focus in the object by a mirror that is fixed as just stated and the distance of the mirror beneath the stage should be made capable of increase (which is easily done by attaching it to a lengthening bar), so as to obtain the requisite focal convergence Still the best effects of objectives of less than $\frac{1}{4}$ inch focus cannot be secured without the aid of an achromatic condenser, interposed between the mirror and the object, so as to bring a larger body of rays to a more exact convergence

When objectives of still higher power are employed, the employment of such a condenser becomes indispensable, and when the highest powers are being used by lamplight, it is desirable to dispense with the mirror altogether, and to place the flame exactly in the optic axis of the microscope The condenser should be an achromatic combination corrected for the ordinary thickness of the glass slip on which the object lies and capable of being so adjusted as to focus the illuminating pencil in the object

As it is often found desirable that an object should be illuminated by central rays alone or that the quantity of light transmitted through it should be reduced (for bringing into view delicate details of structure which are invisible when the object is flooded with light), every microscope should be provided with some means of cutting off the outer rays of the illuminating cone The "diaphragm plate" ordinarily used for this purpose is a disk of black metal pivoted to the under side of the stage, and perforated with a graduated series of apertures of different diameters, any one of which can be brought by the rotation of the disk exactly into the optic axis of the microscope But the required effect can be much more advantageously obtained by the "iris diaphragm," in which a number of converging plates of metal are made so to slide over each other by the motion of a lever or screw that the aperture is either enlarged or diminished, while always remaining practically circular as well as central, and in this manner a continuous view of the object is obtained, with a gradational modification of the light Another method, commonly adopted in German microscopes, is to place a draw tube in the optic axis between the stage and the mirror, and to drop into the top of this tube one of a set of "stops" perforated with apertures of different sizes, this allows a gradational effect to be obtained by raising or lowering the tube, so as to place the stop nearer to or more remote from the object, but it is not nearly so convenient as the iris diaphragm, and the effect of the stop is not nearly so good when it is removed to some distance beneath the object as when it is very near to the under surface of the glass object slide When an achromatic condenser is used, either a diaphragm plate or an iris diaphragm should be placed below its back lens, so as to cut off any required proportion of the outer rays that form its illuminating cone

---

[1] See his paper on "The Relation of Aperture and Power in the Microscope," in *Jour Roy Micros Soc*, 1882, pp 300, 460

[2] See the remarks of Mr Dallinger —whose experience in the application of the highest powers to the study of the minutest living objects is probably greater than that of any living observer —in *Jour Roy Micros Soc*, December 1882 p 853.

Such an arrangement, while suiting all the ordinary requirements of the microscopist who uses the highest powers of his instrument for the purposes of biological investigation (as, for example, in the study of *Bacteria* or of the reproduction of the *Monadina*), does not serve to bring into effective use the special resolving power possessed by objectives of large aperture It has long been known that for the discernment of very closely approximated markings oblique illumination is advantageous,—an objective which exhibits such a diatom valve as *Pleurosigma angulatum* with a smooth unmarked surface when illuminated by the central rays of the achromatic condenser making its characteristic markings (figs 8–11) distinctly visible when the central rays of the condenser are kept back by a stop, and the object is illuminated by its convergent marginal rays only And it has also been practically known for some time that the resolution of lined or dotted tests can be often effected by mirror illumination alone, if the mirror be so mounted as to be able to reflect rays through the object at such obliquity to the optic axis of the microscope as to reach the margin of a wide-angled objective But it has only been since Professor Abbe's researches have given the true theory of "resolution" that the special advantage of oblique illumination has been fully comprehended, and that the best means have been devised for using it effectively Two different systems have now come into use, each of which has its special advantages

One consists in the attachment of the illuminating apparatus (mirror and achromatic condenser) to a "swinging tail piece" (see fig 32), which, moving radially upon a pivot whose axis intersects the optic axis at right angles in the plane of the object, can transmit the illuminating pencil through it at any degree of obliquity that the construction of the stage allows The direction of this pencil being of course limited to one azimuth, it is requisite, in order to bring out its full resolving effect, that the object should be made to rotate, by making the stage that carries it revolve round the optic axis, so that the oblique pencil may impinge upon the lines or other markings of the object in every direction successively It will then be found that the appearances presented by the same object often vary considerably,—one set of lines being shown when the object lies in one azimuth, and another when its azimuth has been changed by rotation through 60°, 90°, or some other angle Various contrivances have also been devised for throwing very oblique illuminating pencils on the object by means of prisms placed beneath the stage

Illumination of at least equal obliquity to that afforded by the swinging tail piece may now, however, be obtained by the use of condensers specially constructed to give a divergence of 170° to the rays which they transmit when used immersionally, by bringing their flat tops into approximation to the under side of the glass slide on which the object is mounted, with the interposition of a film of water or (preferably) of glycerin By using a central stop, marginal rays alone may be allowed to pass, and these will be transmitted through the object in every azimuth at the same time But diaphragms with apertures limiting the transmitted rays to one part of the periphery may be so fixed in a tube beneath the condenser as to be easily made to rotate, thus sending its oblique pencils through the object in every azimuth in succession And where this rotation of the diaphragm brings out two sets of lines at a certain angular interval a diaphragm with two marginal openings at a corresponding angular distance will enable both to be seen at once Numerous arrangements of this kind have been devised by those who devote their special attention to the resolution of difficult diatom tests, but they are of little or no use to those who use the microscope for biological research

For the illumination of the surfaces of opaque objects which must be seen by reflected light the means employed will vary with the focal length of the objective employed For large bright objects viewed under a low magnifying power good ordinary daylight is sufficient, but if the surface of the object is dull, reflecting but little light, the aid of a bull's eye or large bi convex lens must be employed in order to give it sufficient brilliance This aid will always be required by lamplight, and by a proper adjustment of the relative distances of the lamp and the object the rays from the lamp may be made either to spread themselves over a wide area or to converge upon a small spot The former is the method suitable to large objects viewed under a low magnifying power, the latter to the illumination of small objects which are to be examined under objectives of (say) 1 inch or ⅔ inch focus Another method which may be conveniently had recourse to when the microscope is provided with a swinging tail piece is to turn this on its pivot until the concave mirror is brought above the stage, so that rays which it gathers either from natural or artificial sources may be reflected downwards upon the surface of the object

The illumination of an opaque object to be seen with a higher power than the ⅔ or ½ inch objectives was formerly provided for by a concave speculum (termed a Lieberkuhn after its inventor), with a perforation in the centre for the passage of the rays to the objective to which it is fitted,—the curvature of the speculum being so adapted to the focus of the objective which carries it that, when the latter is duly adjusted, the rays reflected upwards around the object from the mirror to the speculum shall converge strongly on the object The various disadvantages of this mode of illumination, however, have caused it to be now generally superseded by other arrangements For powers between 1½ inch and $\frac{4}{10}$ inch, and even for a ¼ or ⅙ inch of small angle and good working distance, nothing is so convenient as the parabolic speculum or side illuminator (F, fig 17) invented by the late Richard Beck This is attached to a spring clip that slides on the tubes of low power objectives, so that its distance from the object and the direction of its reflected pencil are readily adjusted, and for use with higher powers it may be either mounted on a separate arm attached to some part of the stand of the microscope, or may be hung in the manner shown in fig 17 from an "adapter" A interposed between the objective and the body By rotating the collar B and making use of the joints C, C, the lengthening rod D, and the ball and socket E, any position may be given to the speculum F that may best suit the objective with which it is used

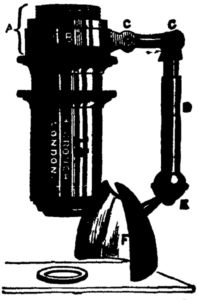


FIG 17 —Beck's Parabolic Side-Illuminator, with Crouch's Adapter

When, however it is desired to illuminate objects to be seen under objectives of high power and very short working distance, side illumination of any kind becomes difficult, though not absolutely impossible,[1] and various modes have been devised for the illumination of the object by means of light sent down upon it, through the objective, from above This is done in the vertical illuminator of Messrs Beck (fig 18)—the original idea of which was first given by the American Professor H L Smith—by a disk of thin glass B, *b*, attached to a milled head by which its angular position may be adjusted, and introduced by a slot A, *e* into the interior of an adapter that is interposed between the objective C, *d* and the nose *c* of the body The light which enters at the lateral aperture A, *a*, falling upon the oblique surface of the disk C, *b*, is reflected downwards, and is concentrated by the lenses of the objective upon the object beneath The lateral aperture may be provided with a diaphragm, with openings of different sizes, for diminishing the false light to which this method is liable, or a screen with a small aperture may be placed between the lamp and the

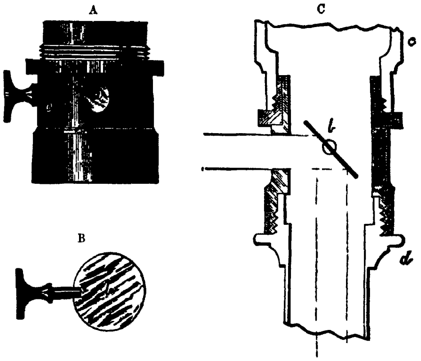


FIG 18 —Beck's Vertical Illuminator

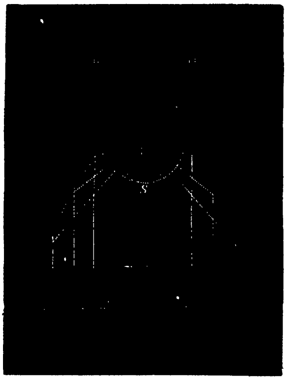
---

[1] See a method devised by Mr James Smith in *Jour Roy Micros Soc*, vol. iii, N S 1880 p 398

illuminator, at any distance that is found to produce the best effects In using this illuminator, the lamp should be placed at a distance of about 8 inches from the aperture, and, when the proper adjustments have been made, the image of the flame should be seen upon the object The illumination of the entire field, or the direction of the light more or less to either side of it, can easily be managed by the interposition of a small condensing lens placed at about the distance of its own focus from the lamp The objects viewed by this mode of illumination with dry front objectives are best uncovered since if they are covered with thin glass, so large a proportion of the light sent down upon them is reflected from the cover (especially when objectives of large angle of aperture are employed) that very little is seen of the objects beneath unless their reflective power is very high With immersion objectives however covered objects may be used Another method of vertical illumination long since devised by Mr Tolles has recently been brought into notice by Professor W A Rogers of Boston (U S) It consists in the introduction of a small rectangular prism at a short distance behind the front combination of the objective so that parallel rays entering its vertical surface pass on between its parallel horizontal surfaces until they meet the inclined surface, by which they are reflected downwards In passing through the front combination of the objective they are deflected towards its axis, but, as their angle of convergence is less than the angle of divergence of the rays proceeding from the object the reflected rays will not meet in the focal point of the lens, but will be so distributed as to illuminate a sufficient area By altering the extent to which the prism is pushed in, or by lifting or depressing its outer end by means of a milled head screw, the field of illumination can be regulated The working of this prism with immersion objectives is stated by Mr Tolles to be peculiarly satisfactory

Black Ground Illumination —There are certain classes of objects which though sufficiently transparent to be seen with light transmitted through them, are best viewed when illuminated by rays of such obliquity as not to pass directly into the objective,—such a proportion of these rays being retained by the object as to render itself luminous, when, all direct light being cut off the general field is perfectly dark This method is particularly effective in the case of such delicate mineral structures as the siliceous tests of *Polycystina* and the "frustules of *Diatomaceæ* And it is one advantage of this kind of illumination that it brings out with considerable effect the solid forms of objects suited to it, even when they are viewed monocularly Two modes of providing this illumination are in use, each of which has its special advantages One consists in placing a central stop either upon or immediately beneath a condenser of wide aperture, which shall cut off all rays save those that, after passing through the object (as in fig 20), diverge at an angle greater than that of the objective used, so that, while the ground is darkened, the object is seen brightly standing out upon it But if the divergence of the rays is but moderate (say 60°), and the angle of the objective is large (say 90°), the most divergent rays of the condenser will enter the marginal portion of the objective, and, the field not being darkened, the black ground effect will not be produced. This method has the great convenience of allowing black ground illumination to be substituted for the ordinary illumination under different powers, without any other change in the apparatus than the turning of a diaphragm plate fitted with stops of different sizes suitable to the several apertures of the objectives, and the modern achromatic condensers of wide aperture can be thus used with objectives of 120° angle

An excellent black ground illumination is also given by the parabolic illuminator (fig 19), originally worked out as a silvered speculum by Mr Wenham, but now made as a paraboloid of glass that reflects to its focus the rays which fall upon its internal surface A diagrammatic section of this instrument, showing the course of the rays through it, is given in fig 20, the shaded portion representing the paraboloid The parallel rays *r*, *r*, *r′* entering its lower surface perpendicularly, pass on until they meet its parabolic surface, on which they fall at such an angle as to be totally reflected by it, and are all directed towards its focus F The top of the paraboloid being ground out into a spherical curve of which F is the centre, the rays in emerging from it undergo no refraction, since each falls perpendicularly upon the part of the surface through which it passes A stop placed at S prevents any of the rays reflected upwards by the mirror from passing to the object, which, being placed at F, is illuminated by the rays reflected into it from all sides of the paraboloid Those rays which pass through it diverge again at various angles, and if the least of these, GFH, be greater than the angle of aperture of the object glass none of them can enter it The stop is attached to a stem of wire, which passes vertically through the paraboloid and terminates in a knob beneath, as shown in fig 19, and by means of this it may be pushed upwards, so as to cut off the less divergent rays in their passage towards the object, thus giving a black ground illumination with objectives of an angle of aperture much wider than GFH In using the paraboloid for delicate objects, the rays which are made to enter it should be parallel, consequently the plane mirror should always be employed, and when, instead of the parallel rays of daylight, we are obliged to use the diverging rays of a lamp, these should be rendered as parallel as possible previously to their reflexion from the mirror, by the interposition of the 'bull's eye so adjusted as to produce this effect There are many cases however, in which the stronger light of the concave mirror is preferable When it is desired that the light should fall on the object from one side only, the circular opening at the bottom of the wide tube that carries the paraboloid may be fitted with a diaphragm adapted to cover all but a certain portion of it, and by giving rotation to this diaphragm, rays of great obliquity may be made to fall upon the object from every azimuth in succession



Figs 19 20 —Wenham's Parabolic Illuminator

In order to adapt this paraboloid to objectives of very wide angle of aperture, a special modification of it, originally devised by Mr Wenham, has been latterly reintroduced under the designation of "immersion paraboloid, with most excellent effect This consists in making the top of the paraboloid flat instead of concave and in interposing a film of glycerin between its surface and the under surface of the glass slide carrying the object Only rays of such extreme obliquity are allowed to pass into the slide as would be totally reflected from its under surface if they fell upon it through air, and, as these illuminate the object without passing into the objective, it can be thus examined under even the highest powers

Binocular Microscopes

Stereoscopic Binoculars —The admirable invention of the stereoscope by Professor Wheatstone has led to a general appreciation of the value of the conjoint use of both eyes, in conveying to the mind a conception of the solid forms of objects such as the use of either eye singly does not generate with the like certainty or effectiveness (see STEREOSCOPE) This conception is the product of the mental combination of the dissimilar perspective projections which our right and left retinæ receive of any object that is sufficiently near the eyes for the formation of two images that are sensibly dissimilar Now it is obvious that a similar difference must exist between the two perspective projections of any object in relief that are formed by the right and left halves of a microscopic objective and that this difference must increase with the angular aperture of the objective And the fact of this difference may be easily made apparent experimentally, by adapting a semicircular "stop to any objective of from 20° to 30° angle in such a manner that it can be turned so as to cover either its right or its left half; for not only will the two images of any projecting object formed by the rays transmitted through the two uncovered halves be found sensibly different, but, if they be photographed or accurately drawn, the "pairing" of their pictures in the stereoscope will bring out the form of the object in vivid relief What is needed, therefore, to give the true stereoscopic effect to a binocular microscope is a means of so bisecting the cone of rays transmitted by the objective that its two lateral halves shall be transmitted the one to the right and the other to the left eye, and that the two images shall be crossed (the image formed by the right half of the objective being sent to the left eye, and that formed by the left half of the objective being sent to the right eye) in order to neutralize the reversing effect of the microscope itself If this crossing does not take place the effect [illegible] prominences It was from a want of due appreciation of this fact that the earlier attempts at constructing a stereoscopic binocular gave representations of objects placed under it, not in their true orthoscopic, but in their pseudoscopic aspect This was the case, for example, with the binocular microscope first devised by

Professor Riddell of New Orleans in 1851, which separated the cone of rays by a pair of rectangular prisms so placed edge to edge above the objective that the rays passing through its right half were reflected horizontally to the right side, to be changed to the vertical direction and sent to the right eye by a lateral rectangular prism, while the rays from the left half of the objective were sent to the left eye in a similar manner. Professor Riddell describes the conversion of relief produced by this arrangement with the ordinary eye piece as making a metal spherule appear as a glass ball silvered on the under side and a crystal of galena like an empty box. And to render the images normal and natural he found himself obliged to use erecting eye pieces, which should produce a second reversal of the images that had been reversed in their first formation.[1] Subsequently, however, Professor Riddell devised and perfected another arrangement giving a true orthoscopic effect, which, after being long disregarded, has been latterly taken up and brought into use by Mr Stephenson. The cone of rays passing upwards from the objective meets a pair of prisms (A, A fig. 21) fixed immediately above its back lens which divides it into two halves; each of these is subjected to internal reflexion from the inner side of the prism through which it passes, and the slight separation of the two prisms at their upper end gives to the two pencils B, B on their emergence from the upper surfaces of the prisms, a divergence which directs them through two obliquely placed bodies to their respective eye pieces. By this internal reflexion a lateral reversal is produced, which neutralizes that of the ordinary microscopic image so that while each eye receives the image formed by its own half of the objective the pairing of the two pictures produces a true orthoscopic effect.[2]

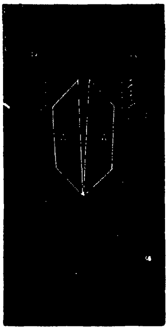


Fig. 21.—Riddell's Binocular Prisms.

About the same date MM. Nachet of Paris succeeded in devising a binocular that should give a true orthoscopic image, by placing above the object glass an equiangular prism (P fig. 22) with one of its surfaces parallel to its back lens, which, receiving the pencils *ab* forming the right half of the cone, internally reflects them obliquely upwards to the left, and in like manner reflects the pencils *a b* from the left half of the cone obliquely upwards to the right. These pencils, passing out of the left and right oblique faces of the prism at right angles (so as not to undergo either refraction or dispersion) enter right and left lateral prisms, also at right angles, and, after being internally reflected by these, pass out vertically, at right angles to their upper surfaces, through two parallel bodies (fig. 23), whose eye pieces bring them to a focus in the right and left eyes respectively. The distance between these bodies may be adjusted to the varying distances between the axes of individual pairs of eyes, by adjusting screws at their base, which vary the distance of the lateral prisms from the central. This instrument gives a theoretically perfect representation of a microscopic object in relief as it would appear if enlarged to the size of its image and brought to within about 10 inches of the eye, and its chief practical defect is that, as the two bodies are parallel, instead of being slightly convergent, it cannot be continuously used without an uncomfortable strain. But, as its performance depends upon the accuracy of the seven plane surfaces of the three prisms, and on the correctness of their relations to each other, it is liable to considerable error from imperfections in its construction; and, as the instrument can only be used for its own special purpose, the observer must be provided with an ordinary single bodied microscope for the examination of objects unsuited to the powers of the binocular. This last objection applies also to Professor Riddell's model.

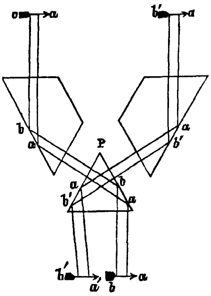


Fig. 22.—Nachet's Binocular Prisms.

It was for these reasons that Mr Wenham, fully impressed with the advantages of stereoscopic vision to the microscopist, set himself to devise a construction by which it might be obtained without the drawbacks inevitable in the working of Riddell's and Nachet's instruments, and he soon succeeded in accomplishing this on a plan which has proved not only convenient but practically satisfactory, notwithstanding its theoretical imperfection. Only the right half of the cone of rays proceeding upwards from the right half of the objective (*a*, fig. 24) is intercepted by a prism placed immediately over that half of its back lens which, by two internal reflexions (as shown in fig. 25) sends its pencils obliquely upwards into the left hand or secondary body L, whilst the pencils of the left half cone pass uninterruptedly into the right hand body R and form an image that suffers no other deterioration than that which results from the halving of the angular aperture and the consequent loss of light. The moderate convergence of the two bodies (which, by varying the angles of the prism may be made greater or less so as to accord with the ordinary convergence of the optic axes in the individual observer) is much more generally suitable than the parallelism of MM. Nachet's earlier instrument, and the adjustment requisite for variation of distance between the eyes can be made by simply lengthening or shortening the bodies by drawing out or pushing in the diverging eye pieces.

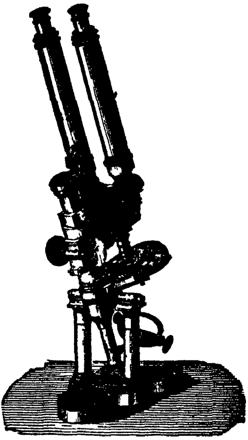


Fig. 23.—Nachet's Binocular Microscope.

It may be fairly objected to Mr Wenham's method (1) that as the rays which pass through the prism and are obliquely reflected into the secondary body traverse a longer distance than those which pass on uninterruptedly into the principal body the image formed by them will be somewhat larger than that which is formed by the other set, and (2) that the image formed by the rays which have been subjected to the action of the prism must be inferior in distinctness to that formed by the uninterrupted half of the cone of rays. But these objections are found to have no practical weight. For it is well known to those who have experimented upon the phenomena of stereoscopic vision (1) that a slight difference in the size of the two pictures is no bar to their perfect combination, and (2) that, if one of the pictures be good, the full effect of relief is given to the image, even though the other picture be faint and imperfect, provided that the outlines of the latter are sufficiently distinct to represent its perspective projection. Hence if instead of the two equally half good pictures which are obtainable by MM. Nachet's original construction we had in Mr Wenham's one good and one indifferent picture, the latter would be decidedly preferable. But, in point of fact, the deterioration of the second picture in Mr Wenham's arrangement is less considerable than that of both pictures in the original arrangement of MM. Nachet, so that the optical performance of the Wenham binocular is in every way superior. It has, in addition these further advantages over the preceding:—first, the greater comfort in using it (especially for some length of time together) which results from the convergence of the axes of the eyes at their usual angle for moderately near objects; second, that this binocular arrangement does not necessitate a special instrument but may be applied to any microscope which is capable of carrying the weight of the secondary body,—the prism being so fixed in a movable frame that it may in a moment be taken out of the tube or replaced therein, so that when it has been removed the principal body acts in every respect as an ordinary microscope, the entire cone of rays passing uninterruptedly into it; and, third, that the simplicity of its construction renders its derangement almost impossible. Hence it is the one most generally preferred by microscopists who use the long bodied English model.

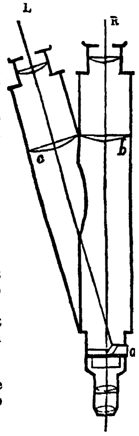


Fig. 24.—Wenham's Stereoscopic Binocular Microscope.

For short bodied Continental microscopes, however, MM. Nachet

---

[1] See Silliman's *Journal* vol. xv. 1853, p. 68; and *Quart. Jour. of Micros. Sci.* vol. i., 1853, p. 236.

[2] *Quart. Jour. of Micros. Sci.*, vol. ii., 1854, p. 18.

have devised an arrangement of two prisms, based on Mr Wenham s fundamental idea of deflecting one half of the cone of rays into a secondary body, whilst the other half proceeds onwards without change of direction into the principal body And it is an interesting feature in this construction that, by a simple change in the position of the dividing prism, the true ' orthoscopic image may be made by a 'conversion of relief, to become "pseudoscopic [1]

The effect of stereoscopic projection may be attained, however, without a double body, by the insertion of a suitably constructed binocular eye piece into the body of any ordinary monocular microscope A plan of this kind was first successfully worked out by Mr Tolles (the very able optician of Boston United States), who interposed a system of prisms similar to that devised by MM Nachet (fig 22), but on a much larger scale between an 'erector (resembling that used in the eye piece of a day telescope) and a pair of ordinary Huygenian eye pieces, the central or dividing prism being placed at or near the plane of the secondary image formed by the erector, while the two eye pieces are placed immediately above the lateral prisms,—the combination thus making that division in the pencils forming the secondary (erected) image which it makes in the Nachet binocular in the pencils emerging from the objective

FIG 25 —Wenham s Binocular Prism

A stereoscopic eye piece of a very different construction has been recently devised by Professor Abbe who, making use, for the division between the two eye pieces of the rays going to form the first image, of an arrangement of prisms essentially similar to that devised by Mr Wenham for his non stereoscopic binocular (fig 27), obtains either an orthoscopic or a pseudoscopic effect by placing on each eye piece a cap with a semicircular diaphragm, so as to extinguish half of each of the cones of rays that form the two retinal images While in one position of the diaphragms true stereoscopic or orthoscopic relief is given, it is sufficient to turn the diaphragms into the opposite position to obtain a pseudoscopic conversion It appears however, that this arrangement though possessing points of great interest in relation to the theory of binocular vision, is not likely to supersede the ordinary Wenham prism

It must be obvious to every one who studies with sufficient attention the conditions under which true stereoscopic relief can be given that no combination of two dissimilar retinal perspectives can be satisfactory unless the visual pictures represent with tolerable distinctness the features of the object that lie in different focal planes This is provided for in ordinary vision by the power of accommodation possessed by the eye which while focussed exactly to any one plane can also include in its visual picture (within certain limits) what is either nearer or more remote Now it seems probable that, as Professor Abbe has urged this power of accommodation comes into play in microscopic stereoscopy, but there can be no question that the visual distinctness of the parts of an object lying within and beyond the focal plane and therefore the completeness of the stereoscopic image, mainly depends upon the "focal depth of the objective employed,—which, as already explained, is a function of its angular aperture When, however objectives of long focus and small aperture are employed in binocular microscopy, although each of the two perspective projections may be fairly distinct throughout, the effect of solid relief will be very inconsiderable, because the pictures are not sufficiently dissimilar to one another —the case being exactly analogous to that of the stereoscopic combination of two photographic portraits taken at an angle of no more than a few degrees from each other Still with an objective of 1½ inches focus and an angular aperture of from 15° to 20°, a very distinct separation is made of the focal planes of transparent sections of structures having no great minuteness of detail —such, especially as injected preparations —the solid forms of their capillary networks being presented to the mind s eye with a vividness that no monocular representation of them can afford When a 1 inch objective of 20° or 25° is used the stereoscopic effect becomes much more satisfactory so that objects of moderate projection (such as many of the siliceous *Polycystina*, *Diatomaceæ* &c) can be seen in nearly their natural projection and, if the focal adjustment is made for a medium plane, with tolerable distinctness both of their nearer and remoter parts With a ⅔ inch of 30° or 35°, the stereoscopic relief becomes more pronounced, but the diminution of the focal depth prevents the several planes of objects in strong relief from being as distinctly seen at the same time A ½ inch objective of about 40° of aperture, however, affords the most satisfactory results with suitable objects,—full stereoscopic relief being gained without exaggeration, so as to present, *e g*, the discoidal diatoms and the smaller *Polycystina* in their true forms, whilst their nearer and more remote parts are seen with sufficient distinctness to require only a very slight adjustment of the focus for their perfect definition Still more minute objects may be well shown by $\frac{1}{4}$ths and ⅕th objectives whose angular aperture does not exceed 50°, but it can be shown both theoretically and practically [3] that the dissimilarity of the two perspective projections of objects in relief formed by objectives of any angle much exceeding 40° is such as to exaggerate the stereoscopic effect, besides which, every enlargement of angular aperture so greatly diminishes the focal depth of the objectives that only those parts of the objects which lie very near the focal plane can be seen with distinctness sufficient for the formation of a good stereoscopic image Hence, for the purposes of minute histological research, the stereoscopic binocular is (in the present writer s opinion) almost valueless, since, if any distinct perspective differentiation can be gained with objectives of the short focus and enlarged angle that are most suitable to such investigations, that differentiation will be so great as to produce a highly exaggerated stereoscopic effect If such objectives be used binocularly at all, they must be so mounted that their back lenses are in very close proximity to the prism, and the (transparent) object must be illuminated by an achromatic condenser of sufficient aperture to send through it pencils of sufficient divergence to produce the secondary image

In regard to the advantage derived from the use of the stereoscopic binocular, with the powers and upon the objects, suitable to produce the true effect of solid form, the writer can unhesitatingly assert, as the result of a long and varied experience, that in no other way could he as certainly or as vividly image those forms to himself, and that in prolonged work upon such subjects he is conscious of a great saving of fatigue, which seems attributable not merely (perhaps not so much) to the conjoint use of both eyes as to the absence of the mental effort required for the interpretation of the microscopic picture, when the solid form of the object has to be ideally constructed from it (chiefly by means of the information obtainable through the focal adjustment), instead of being directly presented to the mind s eye [4]

Non Stereoscopic Binoculars —The great comfort which is experienced by the microscopist in the conjoint use of both eyes has led to the invention of more than one arrangement by which this can be secured when those high powers are required which cannot be employed with the ordinary stereoscopic binocular This is accomplished by Messrs Powell and Lealand by taking advantage of the fact that when a pencil of rays falls obliquely upon the surface of a refracting medium a part of it is reflected without entering that medium at all In the place usually occupied by the Wenham prism they interpose an inclined plate of glass with parallel sides, through which one portion of the rays proceeding upwards from the whole aperture of the objective passes into the principal body with very little change in its course, whilst another portion is reflected from its surface into a rectangular prism so placed as to direct it obliquely upwards into the secondary body (fig 26) Although there is a decided difference in brightness between the two images, that formed by the reflected rays being the fainter, yet there is marvellously little loss of definition in either, even when the $\frac{1}{16}$ inch objective is used The disk and prism are fixed in a short tube, which can be readily substituted in any ordinary binocular microscope for the one containing the Wenham prism

Fig 26

Other arrangements were devised long ago by Mr Wenham,[5] with a view to obtain a greater equality in the amount of light rays forming the two pictures, and he has latterly carried one of these into practical effect, with the advantage that the compound prism of which it consists has so nearly the same shape and size as his ordinary stereoscopic prism as to be capable of being mounted in precisely the same manner, so that the one may be readily exchanged for the other The axial ray *a*, proceeding upwards from the objective, enters the prism ABDEF (fig 27) at right angles to its lower face and passes on to *c*, where it meets the inclined face AB, at which this prism is nearly in contact with the oblique face of the right angled

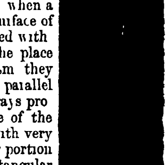


Fig 27

---

[1] See *Trans of Roy Micros Soc* N S vol xv 1867 p 105 and *Monthly Micros Jour* vol i 1869 p 31

[2] See *Jour of Roy Micros Soc* 2d ser vol i 1881 p 298

[3] See *The Microscope and its Revelations* 6th ed pp 42-44

[4] A very elaborate investigation by Professor Abbe ' On the Orthoscopic and Pseudoscopic Effects in the Binocular Microscope in the *Jour of the Roy Micros Soc* 2d ser vol i 1881 p 203

[5] *Transactions of the Micros Soc*, N S vol xiv 1866 p 105

prism ABC. By internal reflexion from the former and external reflexion from the latter about half the beam *b* is reflected within the first prism in the direction *cb*, while the other half proceeds straight onwards through the second prism, in the direction *ca*, so as to pass into the principal body. The reflected half, meeting at *d* the oblique (silvered) surface DE of the first prism, is again reflected in the direction *db*, and, passing out of that prism perpendicularly to its surface AF, proceeds towards the secondary body. The two prisms must not be in absolute contact along the plane AB, since, if they were, Newton's rings would be formed; and much nicety is required in their adjustment, so that the two reflexions may be combined without any blurring of the image in the secondary body.

For the prolonged observation, under high powers, of objects not requiring the extreme of perfection in definition,—such, for example, as the study of the cyclosis in plants,—great advantage is gained from the conjoint use of both eyes by one of the above arrangements.

Mechanical Construction of the Microscope

The optical arrangements on which the working of the compound achromatic microscope depends having now been explained, we have next to consider the mechanical provisions whereby they are brought to bear upon the different purposes which the instrument is destined to serve. Every complete microscope must possess, in addition to the lens or combination of lenses which affords its magnifying power, a stage whereon the object may securely rest, a concave mirror for the illumination of transparent objects from beneath, and a condensing lens for the illumination of opaque objects from above.

1. Now, in whatever mode these may be connected with each other, it is essential that the optical part and the stage should be so disposed as either to be altogether free from tendency to vibration or to vibrate together; since it is obvious that any movement of one, in which the other does not partake, will be augmented to the eye of the observer in proportion to the magnifying power employed. In a badly constructed instrument, even though placed upon a steady table resting upon the firm floor of a well built house, when high powers are used, the object is seen to oscillate so rapidly at the slightest tremor—such as that caused by a person walking across the room, or by a carriage rolling by in the street—as to be frequently almost indistinguishable; whereas in a well constructed instrument scarcely any perceptible effect will be produced by even greater disturbances. Hence in the choice of a microscope, it should always be subjected to this test, and should be unhesitatingly rejected if the result be unfavourable. If the instrument should be found free from fault when thus tested with high powers its steadiness with low powers may be assumed; but on the other hand though a microscope may give an image free from perceptible tremor when the lower powers only are employed, it may be quite unfit for use with the higher. The method still adopted by some makers, of supporting the body by its base alone is the worst possible especially for the long body of the large English model, since any vibration of its lower part is exaggerated at its ocular end. The firmer the support of the body along its length the less tremor will be seen in the microscopic image.

2. The next requisite is a capability of accurate adjustment to every variety of focal distance, without movement of the object. It is a principle universally recognized in the construction of [illegible] microscopes that the stage whereon the object is placed should be a fixture, the movement by which the focus is to be adjusted being given to the optical portion. This movement should be such as to allow free range from a minute fraction of an inch to three or four inches, with equal power of obtaining a delicate adjustment at any part. It should also be so accurate that the optic axis of the instrument should not be in the least altered by any movement in a vertical direction, so that, if an object be brought into the centre of the field with a low power, and a higher power be then substituted, the object should be found in the centre of its field, notwithstanding the great alteration in the focus. In this way much time may often be saved by employing a low power as a "finder" for an object to be examined by a higher one; and when an object is being viewed by a succession of powers little or no readjustment of its place on the stage should be required. A rack and pinion adjustment, if it be made to work both tightly and smoothly, answers sufficiently well for the focal adjustment, when objectives of low power only are employed. But for any lenses whose focus is less than half an inch a "fine adjustment," or "slow motion," by means of a screw movement operating either on the object glass alone or on the entire body (preferably on the latter), is of great value; and for the highest powers it is quite indispensable. It is essential that in this motion there should be no "lost time," and that its working should not produce any "twist" or displacement of the image. In some microscopes which are provided with a fine adjustment the rack and pinion movement is dispensed with, the "coarse adjustment" being given by merely sliding the body up and down in the socket which grasps it; but this plan is only admissible where, for the sake of extreme cheapness or portability, the instrument has to be reduced to the form of utmost simplicity, as in figs. 28, 29.

3. Scarcely less important than the preceding requisite, in the case of the compound microscope, especially with the long body of the ordinary English model, is the capability of being placed in either a vertical or a horizontal position, or at any angle with the horizon, without deranging the adjustment of its parts to each other, and without placing the eye piece in such a position as to be inconvenient to the observer. It is certainly a matter of surprise that some microscopists, especially on the Continent, should still forego the advantages of the inclined position, these being attainable by a very small addition to the cost of the instrument; but the inconvenience of the vertical arrangement is much less when the body of the microscope is short, as in the ordinary Continental model; and there are many cases in which it is absolutely necessary that the stage should be horizontal. This position, however, can at any time be given to the stage of the inclining microscope, by bringing the optic axis of the instrument into the vertical direction. In ordinary cases, an inclination of the body at an angle of about 55° to the horizon will usually be found most convenient for unconstrained observation; and the instrument should be so constructed as when thus inclined, to give to the stage such an elevation above the table that, when the hands are employed at it, the arms may rest conveniently upon the table. In this manner a degree of support is attained which gives such free play to the muscles of the hands that movements of the greatest nicety may be executed by them, and the fatigue of long continued observation is greatly diminished. When the ordinary camera lucida[1] is used for drawing or measuring, it is requisite that the microscope should be placed horizontally. It ought, therefore, to be made capable of every such variety of position; and the stage must of course be provided with some means of holding the object, whenever it is itself placed in such a position that the object would slip down unless sustained.

4. The last principle on which we shall here dwell, as essential to the value of a microscope designed for ordinary work, is simplicity in the construction and adjustment of every part. Many ingenious mechanical devices have been invented and executed for the purpose of overcoming difficulties which are in themselves really trivial. A moderate amount of dexterity in the use of the hands is sufficient to render most of these superfluous; and without such dexterity no one, even with the most complete mechanical facilities, will ever become a good microscopist. There is, of course, a limit to this simplification; and no arrangement can be objected to on this score which gives advantages in the examination of difficult objects, or in the determination of doubtful questions such as no simpler means can afford. The meaning of this distinction will become apparent if it be applied to the cases of the mechanical stage and the achromatic condenser. For, although the mechanical stage may be considered a valuable aid in observation, as facilitating the finding of a minute object or the examination of the entire surface of a large one, yet it adds nothing to the clearness of our view of either and its place may in great degree be supplied by the fingers of a good manipulator. On the other hand, the use of the achromatic condenser not only contributes very materially, but is absolutely indispensable, to the formation of a perfect image, in the case of many objects of a difficult class; the want of it cannot be compensated by the most dexterous use of the ordinary appliances; and consequently, although it may fairly be considered superfluous as regards a large proportion of the purposes to which the microscope is directed, whether for investigation or for display, yet as regards the particular objects just alluded to it is a no less necessary part of the instrument than the achromatic objective itself.

As a typical example of the simplest form of compound microscope that is suitable for scientific research,—which, with various modifications of detail, is the one generally employed on the Continent,—the *Microscope de dissection et d'observation* (fig. 28) of M. Nachet, especially as constructed for portability (figs. 29–31), seems particularly worthy of description. In its vertical form (fig. 28) the solid foot to which the mirror is pivoted gives support to the pillar F, to the top of which the stage P, having a diaphragm plate beneath it, is firmly attached. On the top of this pillar the tubular stem A is fitted in such a manner that it may be removed by unscrewing the large milled head L,—though, when this is well screwed down, the stem stands quite firmly. This stem bears at its summit a short horizontal arm, which carries a strong vertical tube that firmly grasps the "body" of the microscope, while permitting this to be easily slid upwards or downwards, so as to make a "coarse adjustment" of the focus. The "fine adjustment" is made by turning the milled head V, which either presses down the outer tube of the stem, or allows it to be raised by the upward pressure of a strong spiral spring in its interior. By unscrewing the milled head L, the stem A with its arm and compound body can be detached from the pillar; and, a small light arm H holding either single lenses or doublets being slid into this, a convenient dissecting microscope is thus provided. The only drawback in the construction of this simple model is its not being provided with a joint for the inclination of the body but this is introduced into the portable form of the instrument shown in fig 29 the basal portion of which (fig 30) can be used like that of the preceding model as a simple microscope and is a most ingenious construction can be so folded as to lie flat in a shallow case (fig 31) that holds also the upper part with the objectives of both the simple and the compound body. M Nachet now connects his objectives with the body of his microscopes not by a screw but by a cylindrical fitting held in place by the pressure of a spring clip against a projecting shoulder. This method not only allows one objective to be removed and replaced by another much more readily than does the screw fitting but also renders the centring of different objectives more exactly conformable. It may be safely affirmed that a very large proportion of the microscopic work of the last half century which has given an entirely new aspect to biological science has been done by instruments of this simple Continental type.

---

[1] A camera lucida adapted for use with the vertical microscope has been devised by M. Nachet.

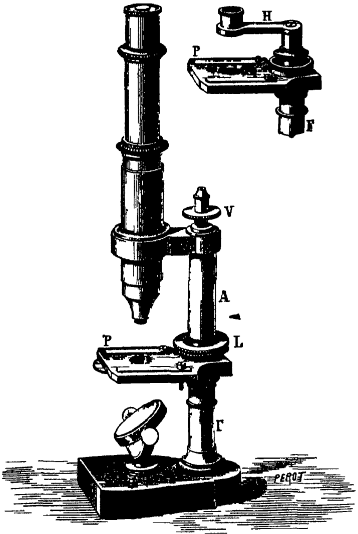


Fig 28 —Nachet's Combined Simple and Compound Microscope

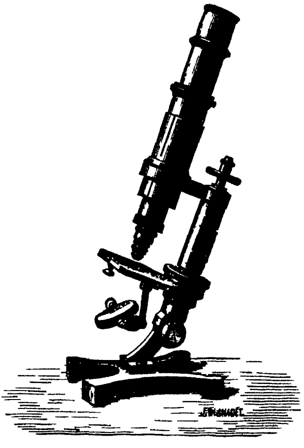


Fig 29 —Nachet's Portable Compound Microscope

A larger model, however was from the first adopted by English opticians and as a typical example of the general plan of construction now most followed both in England and in the United States the improved Jackson Zentmayer microscope of Messrs Ross (fig 32) may be appropriately selected. The tripod base of this instrument carries two pillars between which is swung upon a horizontal axis (capable of being fixed in any position by a tightening screw) a solid ' limb, with which all the other parts of the instrument are connected —a plan of construction originally devised by Mr George Jackson. The binocular body having at its lower end as in fig 24) an opening into which either of the Wenham prisms can be inserted and at its top a rack movement for adjusting the eyepieces to the distance between the eyes of the observer is attached to a racked slide, which is so acted on by the large double milled head in the upper part of the limb as to give a quick upward or downward motion to the body while the slow motion or fine adjustment is given by means of the vertical micrometer screw at the back of the limb which raises or lowers a second slide behind the rack[1]. The stage is supported upon a firm ring which is immovably fixed not to the limb but to a strong conical pivot which passes through the limb to be clamped by a screw nut at its back —the purpose of this being to allow the whole stage to be inclined to one side or the other at any angle so that a solid object may be viewed sideways or from below as well as from above. Upon this ring the stage rotates horizontally, its angular movement being measured by a graduated scale and vernier at its edge and it can be fixed in any azimuth by a clamping screw beneath. Rectangular movement is given to the traversing platform which carries the object by two milled heads on the right of the stage the whole construction of which is adapted to allow light of extreme obliquity to be thrown upon the object from beneath. On the strong pivot by which the stage is

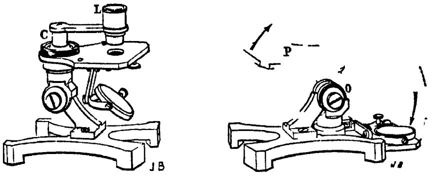


Fig 30 —Nachet's Portable Dissecting Microscope on the left as set up for use on the right as having the stage P turned back upon the joint O so as to lie flat on the bottom of the case

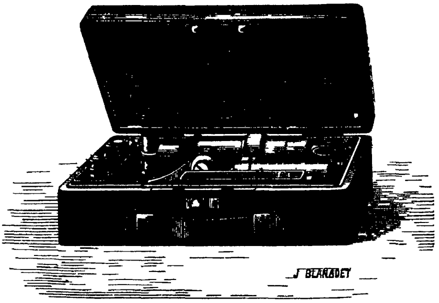


Fig 31 —Nachet's Portable Compound and Dissecting Microscope as packed in case

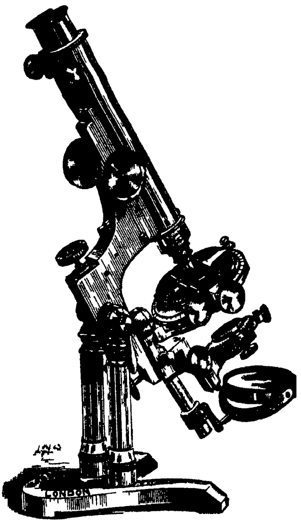


Fig 32 —Ross's Jackson Zentmayer Compound Microscope

attached to the limb (the axis of which passes through the point at which the object plane is intersected by the optic axis of the body) is hung the swinging tail piece invented by Mr Zentmayer of Philadelphia, which, carrying the whole illuminating apparatus, may be so set as to give to the axis of the illuminating pencil any required degree of obliquity. To the upper part of it is attached a rack and pinion movement carrying the "substage," which is provided with two milled headed screws for centring it precisely with the microscope body. Into this may be fitted the achromatic condenser, parabolic illuminator, polarizing prism, or any other kind of illuminating apparatus; whilst at its lower end it carries the mirror, the position of which may be varied by sliding its fitting up or down the "tail piece," or by turning the arm which carries it to one side or the other; while, if direct illumination from a lamp should be preferred, it may be turned altogether aside. By swinging the tail piece round above the stage oblique light may be reflected from the mirror, through the condenser, upon the upper surfaces of objects. The condenser usually fitted to this instrument is of about $\frac{4}{10}$ inch focus, with a large back lens, behind which are placed an iris diaphragm for reducing the light to the central rays, and a diaphragm plate with apertures of the various forms most suited for the resolution of lined objects by oblique rays.

---

[1] In the older form of construction still retained by some makers the fine adjustment acts directly on the objective the fitting of which is made to slide up and down within the nose of the body but this plan is attended with many disadvantages.

No instrument, in the writer's judgment, is better adapted than this for the highest purposes of microscopical research. It works admirably with every power from the lowest to the highest, and is capable of receiving any one of the numerous pieces of apparatus which have been devised for special researches of various kinds. The detailed description of these not being here admissible, it will be sufficient to indicate the polariscope and the spectroscope as the most important of these accessories.

MICROMETRY.

The microscopist has constant need of some means of taking exact measurements of the dimensions of the minute objects or parts of objects, on the study of which he is engaged; and the accuracy of the operation will of course be proportioned to the correctness of the standard used, and the care with which it is applied.

The instruments employed in microscopic micrometry are of two kinds, the measurement being taken in one by the rotation of a fine screw with a divided milled head, whilst in the other a slip of glass ruled with lines at fixed distances gives a scale which forms a basis of computation. Each of these has its advantages and its disadvantages.

The stage micrometer constructed by Fraunhofer was formerly much used by Continental microscopists, and has the advantage of indicating the actual dimensions of the objects to be measured; but it has the two special disadvantages that a sufficiently small value cannot be conveniently given to its divisions, and that any error in its construction and working is augmented by the whole magnifying power employed. This instrument has now, however, almost entirely given place to one of those to be next described.

The screw micrometer ordinarily used in astronomical measurements (see MICROMETER) can be adapted to the eye piece of the microscope in a manner essentially the same as that in which it is applied to the telescope,—its two parallel threads—of which one is fixed and the other made to approach towards or recede from this by the turning of the screw—being placed in the focus of the eye glass, and being therefore seen as lines crossing its field of view. The object is so focussed that its image is formed in the same plane, and the latter being brought into such a position that one of its ends or margins lies in optical contact with the fixed line, the screw is turned so as to bring the movable line into the like coincidence with the other. But the distance between the lines as given by the number of divisions of the micrometer will here be the measurement, not of the object itself but of its magnified image; and the value of these divisions therefore will depend upon the amplification given by the particular objective used. Thus suppose each division of the micrometer to have an actual value of $\frac{1}{10000}$th of an inch, and the visual image to have one hundred times the linear dimensions of the object, the theoretical micrometric value of each division would be $\frac{1}{100}$th of $\frac{1}{10000}$th, or one millionth, of an inch,—a degree of minuteness however not practically attainable. It is necessary, moreover, to determine the micrometric value of the divisions of the micrometer, not only for every objective, but for variations in the conditions under which that objective may be employed, as regards the length of the tube or body of the microscope, which is varied not only by the draw tube but also in many cases in the working of the fine adjustment or slow motion, and also, in the case of the large angled powers furnished with adjustment for thickness of the covering glass, for the degree of separation of the front from the back glasses of the objective, which makes a very sensible difference in its magnifying power. This determination is made by means of a divided glass stage micrometer put in the place of the object, so that the lines ruled upon it at fixed intervals shall be projected upon the field of view. The stage micrometer is usually ruled either to 1000ths of an inch or 100ths of a millimetre, and it is convenient that one of the divisions of its image should be made to coincide exactly with a certain number of divisions of the screw micrometer. This may be done by lengthening the draw tube, so as to increase the amplification of the scale until coincidence has been reached; and the exact amount of this lengthening should be noted,—as should also the precise position of the milled head of the slow motion (if it acts on the objective, instead of on the body as a whole), and of the adjusting screw collar of the objective itself. Thus, if two lines of the stage-micrometer separated by 1000th of an inch be brought into coincidence with the two threads of the eye piece micrometer, separated by forty divisions of the screw milled head, the value of each of those divisions is $\frac{1}{40000}$th of an inch. If the above conditions be precisely recorded for each objective used in micrometry, the micrometric value of the divisions remains the same for that objective, whenever it is employed under the same conditions.

The errors to which micrometers are subject arise (1) from inequalities in the ruling of the stage micrometer, (2) from irregularities in the screw of the eye piece micrometer, (3) from "lost time" in its working, and (4) from the thickness of its threads. In order to eliminate the first and second, it is well to determine the relation of the divisions of the two micrometers by the comparison of a considerable number of both; the third proceeds from an imperfection of workmanship which, if it shows itself sensibly, entirely destroys the value of the instrument, while the fourth can be rectified by the exercise of skill and judgment on the part of the observer. For, if the micrometer is so constructed as to read zero when one thread lies exactly upon the other, its divisions indicate the distance between the axes of these threads when separated; and the dimensions of any object (such as a blood corpuscle) lying between their borders will obviously be too great by half the thickness of the two threads, that is, by the entire thickness of one thread. When on the other hand, the measurement is being made (as of the distances of the striae on diatoms) by the coincidence between certain lines on the object and the axes of the threads of the micrometer, the dimensions indicated by the divisions of the screw milled head will be correct.

The costliness of a well constructed screw micrometer being a formidable obstacle to its general use, a simpler method (devised by Mr George Jackson) is more commonly adopted, which consists in the insertion of a ruled glass scale into the focus of an ordinary Huygenian eye piece, so that its lines are projected on the field of view. This scale (ruled, like an ordinary measure, with every fifth line long and every tenth line double the length of the fifth) is fixed in a brass inner frame that has a slight motion in the direction of its length within an outer frame; and this last being introduced through a pair of slits into the eye piece just above the diaphragm, and being made to occupy the centre of the field, is brought exactly into focus by unscrewing the eye glass as far as may be requisite. When the image of the object to be measured is brought by the focal adjustment of the object glass into the same plane, a small pushing screw at the end of the micrometer (whose action is antagonized by a spring at the other end) is turned until one of the long divisions of the scale is brought into optical contact with one edge of the image of the object to be measured, and the number of divisions is then counted to its other edge,—the operation being exactly that of laying a rule across the real object if enlarged to the size of its image. The micrometric value of each division of this eye piece scale must be carefully ascertained for each objective, as in the case of the screw micrometer, the error arising from inequality of its divisions being eliminated as far as possible by taking an average of several. The principal point of inferiority in this form of micrometer is that, as its divisions cannot be made of nearly so small a value as those of the screw micrometer, an estimate of fractional parts of them often becomes necessary, which is objectionable as involving an additional source of error. To meet this objection, Hartnack has introduced the diagonal scale used in mathematical instruments before the invention of the vernier.

Another mode of making micrometric measurements which for some purposes has considerable advantages, is to employ a stage micrometer in combination with some form of camera lucida attached to the eye piece of the microscope, so that the image of its divisions may be projected upon the same surface as that on which the image of the object is thrown. By first using the ruled stage micrometer and marking on the paper the average distance of its lines as seen in the central part of the field, and then ruling the paper accordingly, the micrometric value of the divisions so projected may be exactly determined for the objective employed and the distance of the drawing plane from the eye piece,—so that when the image of any object is projected under the same conditions the dimensions of that image or of any parts of it can be exactly measured upon the divided scale previously projected, and the true dimensions of the object thus easily ascertained. If for example the lines of a stage micrometer ruled to the thousandth of an inch should, when thus projected, fall at a distance of an inch apart, then the application of an ordinary scale of inches (divided into tenths) to the image of an object projected by the same objective and on the same plane would give its real dimensions in thousandths of an inch while the tenths of the inch scale would represent a real dimension of as many ten thousandths It is often desirable to make such measurements from careful tracings of the outlines of objects rather than from the visual images,—this plan being especially advantageous when the exact dimensions of many similar objects have to be compared, as in the case of blood corpuscles precise measurements of which are not unfrequently required in judicial inquiries It was by the use of this method that the late Mr Gulliver made his admirable series of measurements of the average and extreme dimensions of the blood corpuscles of different animals And more recently Mr Dallinger has shown,—by first making a very fine camera lucida tracing of *Bacterium termo* under an amplification of 2000 diameters, and measuring the breadth of its body in the mode above indicated (which gave it as $\frac{1}{20000}$th of an inch), and then by magnifying his tracing from five to ten diameters, and comparing, by means of the screw micrometer, the breadth of the flagellum with that of the body (which last proved to be just ten times as great),—that, although the theoretical limit of resolving power for closely approximated lines is $\frac{1}{146528}$th of an inch a semitransparent filament whose breadth is not greater than $\frac{1}{200000}$th of an inch may be clearly discerned, and even measured with a close approximation to accuracy (*Journ of Royal Micros. Society*, vol i, 1879, p 169) (W B C)

MIDAS, king of Phrygia, is one of those half legendary heroes in whom religious legends have gathered round a real person The name Midas the king, MIΔAI ΓANAKTEI, occurs on a very ancient tomb in the valley of the Sangarius, the legendary seat of the Phrygian kingdom (*Iliad* iii 189) The Phrygian monarchy was destroyed by the Cimmerians about 670 B C, and the last king Midas committed suicide by drinking bull's blood The name Midas became in Greek tradition the representative of this ancient dynasty, but all that is told of him is religious myth He is a figure in the cycle of Cybele legends, the son of the goddess and her first priest He is also closely connected with the cultus of Dionysus, like the two heroic personages Marsyas and Silenus The Midas legend was known on Mount Bermius in Macedonia, and must at one time have existed in Greece, two cities Midea, in Argolis and in Bœotia, recall the Phrygian city Midæum

See Herod viii 138, Xen *Anab*, i 2, 13 Paus i 45 &c

MIDDELBURG, in Holland, the ancient capital of the province of Zealand, situated in the middle of the island of Walcheren, is mentioned as early as 1153, and receives the title "town in a charter granted it in 1227 It has all the characteristics of an old and worn out place The population (25,000 in 1739) had sunk to 12,000 or 13,000 by the beginning of the 19th century, and has only begun recently to increase again, being 15,939 in 1882 The dwelling houses, which in 1739 were about 3800, are now but 3000, and of these about 600 are unoccupied The vast warehouses and imposing mansions once belonging to wealthy families, which have either died out or left the place, call up the memory of that prosperity which Middelburg enjoyed before its extensive trade, with the East and West Indies, with England and Flanders, was ruined by the war with England and the French occupation By the opening of the railway (1872) and of the ship canal (1873) to Flushing Middelburg was lifted out of its isolation, and, with the assistance of the chamber of commerce, manufacturing industries (iron, machinery, furniture, oil cigars, &c) were established, but the prosperity anticipated for Flushing, and consequently for Middelburg, remains unrealized One of the chief sights of Middelburg is the splendid town house, for the most part erected in 1512–13, with its front gable adorned with twenty five statues of counts and countesses of Holland and Zealand, it contains the archives, and a most valuable antiquarian and historical collection The abbey, begun in 1150, has frequently been the residence of royal visitors (Maximilian, Philip the Fair, Charles V and so on down to Napoleon I, and William I, II, and III) part of it is now an hotel, and part of it is occupied by the provincial authorities The great hall of the building, in which the states of Zealand assemble, is adorned with beautiful tapestries by Jan de Maecht, representing the heroic feats of the men of Zealand in the contest with Spain What was formerly the nave of the abbey church is now the New Church, and the ancient choir constitutes the Choir Church The former contains a fine pulpit resting on an eagle, the monument of William, king of the Romans (d 1256), and the tombs of Jan and Cornelis Evertsen, two naval heroes who fell in the war against England in 1666, the latter has the monuments of the learned Hadrian Junius and of Jan Pieterszoon The provincial court, the corn exchange, the Hof St Joris and the Hof St Sebastian (formerly buildings belonging to the guilds of archers, and now places of amusement) deserve mention The great museum of Zealand antiquities, collected by the Zealand Society of Arts and Sciences (founded at Flushing in 1769 and transferred to Middelburg in 1801), shows that the town is the intellectual centre of the province

The principal facts in the history of Middelburg are the sieges by the Flemings in 1288 1296 and 1303 (the last resulting in the capture of the town by Guy of Dampierre) the recovery of the town from the Spaniards in 1574, after an investment of nearly two years the frequent disturbances among the townsfolk in the 17th and 18th centuries the surrender to the English in 1809 and the arrival and departure of the French in 1809 and 1814

MIDDLEBOROUGH, a town of the United States, in Plymouth county, Massachusetts, 34 miles south of Boston It has a handsome town hall and a public library, manufactures woollen goods, straw goods, shovels, shoes, carriages, &c, and in 1880 had 5237 inhabitants

MIDDLESBROUGH, situated near the mouth of the Tees, on its south bank, in the North Riding of Yorkshire, has now become the principal seat of the English iron trade It is a municipal and parliamentary borough, locally governed by a mayor and corporation, and returns a member to parliament The earlier history of the place is meagre Where Middlesbrough now stands (Graves's *History of Cleveland*) there were at one time a small chapel and priory founded by Robert de Brus of Skelton Castle These were dedicated to St Hilda, and with some lands were given by De Brus to the abbey of St Hilda at Whitby in 1130 The priory fell into ruins at the time of the Reformation, and no trace now remains beyond some stones built into the wall of a brewery The mayor's chain also is made from a fragment In 1801 there were upon the site of Middlesbrough only four farm houses In 1829 a company styling itself the Middlesbrough Owners bought 500 acres of land, and commenced building the town In 1830 the Stockton and Darlington Railway was extended from Stockton to Middlesbrough, four years later the town was lighted with gas, and after six years more a public market was established The census of 1831 showed the population to be 154, that of 1841 showed 5709 In 1842 the opening of the docks gave additional importance to the town First containing an area of 9 acres, they were extended in 1872 to 12 acres, with 1700 feet of quays Vessels of 3000 tons burden can be accommodated From the year 1851, when J Vaughan discovered the presence of ironstone in the Eston Hills, the town advanced with rapid strides When the jubilee of the town was held in 1881 (a year late) the population had risen to 55,934, the area to 2731 acres, and the rateable value to £140,000, the population of the parliamentary borough (area 4715 acres) being 72,145 In the district there are upwards of

180 blast furnaces, besides large iron and steel works, and the Thomas Gilchrist process of making steel promises for Middlesbrough importance in the future as a steel entrepot. The make of pig iron in 1880 was 1,991,032 tons. There are also shipbuilding, potteries, chemical works, and a salt trade. Middlesbrough is well laid out, nearly all the streets lying at right angles to one another. Many of the churches and the exchange are handsome buildings, while the station of the North Eastern Railway is probably the finest in the north of England. A splendid park of 72 acres, the gift of the late H. F. W. Bolckow, adds greatly to the amenity of the town.

Plate III. MIDDLESEX, an inland county in the south east of England, lying between 51° 25′ and 51° 40′ N. lat., and between 0′ and 0° 36′ W. long. On the south it is divided from Surrey and Kent by the Thames, on the east from Essex by the Lea, on the west from Buckinghamshire by the Colne, and on the north from Hertfordshire by a partly artificial and very irregular line. Although with the exception of Rutland it is the smallest county in England, its population is exceeded by that of Lancashire only. Its total area is 181,317 acres, of which 2592 acres are common or waste lands. The longest straight line that can be drawn in the county is one of nearly 28 miles from the north eastern extremity near Waltham Abbey to the south western at Staines. From north to south in the broadest part the distance is about 15 miles.

Surface and Geology.—The greater portion of the county is flat, although there are sufficient undulations to allow of a proper drainage of the land. A range of hills runs along the Hertfordshire border by Barnet, Elstree, Stanmore, and Pinner, averaging 400 feet in height; another range occupies the ground just north of London by Hornsey, Highgate, and Hampstead; Harrow occupies an isolated eminence between the two ranges.

The county lies entirely within the basin of the Thames, and the London Clay extends over a large portion of the surface. This formation stretches from the mouth of the estuary of the Thames to the neighbourhood of Marlborough. It attains its greatest breadth (little short of 30 miles) in the neighbourhood of London, and extends northward until it is lost beneath the drift of Suffolk and Norfolk. The following is a table of the various beds of rock which occur at the surface, with their greatest thickness (in feet) in the district:—

Alluvium (recent river deposits)	15
Post Pliocene Tertiaries.	
Post glacial beds (brick earth, gravel, &c.)	50
Glacial drift (boulder clay, gravel, &c.)	80
Eocene Tertiaries.	
Lower Bagshot sands	100
London Clay	420
Woolwich and Reading beds	90
Cretaceous.	
Chalk with flints	800

Chalk comes to the surface in so very few places that it is scarcely worth mention. It is seen near Harefield and on the north west side of South Mimms. The depth from the surface to the chalk varies greatly in different parts of the county. This has been proved by the borings for wells; thus at Isleworth the depth is 400 feet and at Hampstead 378, while at Ruislip it is 76 feet and at Pinner only 60. The Reading beds (plastic clays) are brought to the surface at Windsor. They follow roughly the course of the river Colne from the north of Uxbridge along the flank of the hills north eastward, but are sometimes cut back southward along small side valleys. An outlying mass is exposed at Pinner. The Bagshot sands, consisting of gravel and sand permeable to water, once stretched over the whole extent of the London Clay, but they are now to be found only on the high grounds at Hampstead, Highgate, and Harrow. A corner of the main mass enters the south west corner of the county near Littleton. Beds of brick earth occur in the drift between West Drayton and Uxbridge.

Several deep borings in the London basin prove the existence beneath the chalk of beds which do not crop out in Middlesex. Three of these are in the county, and the most interesting is that at Meux's Brewery, Tottenham Court Road (about 1146 feet), which passes through the following formations:—gravel and clay, 21 feet; London Clay, 64 feet; Reading beds, 51 feet; Thanet sand, 21 feet; chalk, 655 feet; Upper Greensand, 28 feet; gault, 160 feet; Lower Greensand, 64 feet; Devonian, 80 feet.

Rivers and Canals.—The Thames is very tortuous in the 44 miles of its course from Staines to Blackwall, and makes a remarkable bend at the eastern limit of the county where it forms the so called Isle of Dogs. The width at Staines is 200 feet, at Chiswick opposite Barnes 340 feet, at Hammersmith 525 feet, at Fulham 820 feet, at Westminster Bridge 1100 feet, but at London Bridge it is less than 800 feet; above the junction of the Lea at the Isle of Dogs the width is 1350 feet. The ordinary rise of the tide at London Bridge is 16 feet, and the tideway ends at Teddington. The port of London begins below London Bridge, and the channel for from 2 to 3 miles is called the Pool.

The Colne from Hertfordshire enters Middlesex at the north western corner of the county. It then runs south, joining the Thames at Staines, and in its course divides Middlesex from Buckinghamshire for 15 miles. After the river leaves Uxbridge it divides out into several small channels. The Lea from Hertfordshire enters Middlesex at the north eastern corner of the county near Waltham Abbey. It runs south, dividing Middlesex from Essex for 15 miles, and falls into the Thames at Bow Creek. Several branches flow off from the river during its course. The Brent from Hertfordshire enters Middlesex near Finchley. It takes a circuitous direction southward through the middle of the county by Hendon, Kingsbury, Twyford, Greenford, and Hanwell to the town of Brentford, where it unites with the Thames. Where the river crosses the Edgeware Road (about 3 miles south of the town of Edgeware) it is expanded by artificial means into an extensive reservoir. The Cran (or Yedding Brook) rises in the district between Harrow and Pinner, and flows under Cranford Bridge; it crosses Hounslow Heath, and bends round to Twickenham and Isleworth, where in a divided stream it falls into the Thames.

There were several other small streams in the neighbourhood of London which have left their mark in the names of places, but which are now merely sewers, such as the Wallbrook, the Westbourn, the Tyburn, the Fleet river, &c. The last mentioned, which runs into the Thames near Blackfriars Bridge, was formerly navigable as far as Holborn Bridge; but the Fleet Ditch, as it was then called, having become in the last century a dangerous nuisance, the lord mayor and citizens were empowered by Act of Parliament to arch it over. The work was commenced in 1734, and in 1737 Fleet market, occupying the site of the space from Holborn Bridge to Fleet Bridge, was opened to the public. The New River, an artificial water-course constructed by Sir Hugh Myddelton in the reign of James I. to supply London with water, runs through the county from north to south a little to the west of the river Lea. It derives its waters from the springs of Amwell and Chadwell, increased by a cut from the Lea in the neighbourhood of Ware, and enters Middlesex from Hertfordshire about 2 miles north of Enfield. It passes Enfield, Tottenham, Hornsey, and Stoke Newington, and is received into the reservoir in Clerkenwell known as the New River Head.

The Grand Junction Canal leaves the Thames at Brentford, proceeds in a westerly direction by way of Hanwell and Cranford to West Drayton, thence in a northerly direction it follows the valley of the Colne It passes Uxbridge, and after leaving the county takes its further course by Rickmansworth through Hertfordshire The Paddington Canal leaves the Grand Junction Canal at Cranford, and passes Northolt, Apperton, Twyford (where it is carried over the Brent by an aqueduct), and Kensal Green At Paddington it joins the Regent's Canal, which passes the north of Regent's Park, and after proceeding through the eastern portions of London joins the Thames at Limehouse The Regent's Canal is joined to the river Lea by means of Sir George Duckett's Canal, and thus there is a through communication from the north eastern corner of the county to the south eastern corner, thence from east to west, and northward to the north west corner

Climate, Soil, Agriculture, &c—The climate of the county is equable and good, and the shelter of the northern hills makes the air mild Highgate, Hampstead, and some other parts are supposed to be specially healthy, and are recommended for invalids by the medical profession

The heavy poor clay in the north and north western portion of Middlesex is chiefly covered with permanent grass In some parts it has been made fit for arable cultivation by the addition of chalk, lime, and ashes The rich deposits from the Thames have formed a soil which when well manured is specially suitable for market gardens From its nearness to London the district has long been famous for high farming, and the divisions devoted to different kinds of farming are well marked The greater part of Gore and Ossulston hundreds, portions of Spelthorne and Edmonton hundreds, and a strip down the western side of Elthorne hundred are devoted to meadow and pasture The arable land is chiefly found on the western side, and between the Great Western Railway and the Thames It is also to be seen in the north western district With the constant increase of London, houses have encroached upon the fields, and most of the market gardens which were situated in the neighbourhood of Islington and Hackney have disappeared The strip of land by the Thames from Brentford to Chelsea was given up almost entirely to market gardens, but Fulham is fast being built over

According to the returns for 1882 the area occupied by grain and green crops grass &c was 116 470 acres Of this amount 16,337 acres were under corn crops (wheat 6410 barley, 3083 oats 3895 and beans and pease 2636) 13 451 under green crops (including potatoes 3019 turnips 1539, mangolds 1692 cabbage &c, 1188) 3025 under clover and grasses sown in rotation and 82 782 under permanent pasture Orchards occupied 3419 acres, market gardens, 6900 nursery grounds, 447 and woods 2382 In the same year the horses numbered 5939 (4188 used for agricultural purposes) cattle, 23 283 (cows 15 390) sheep 23 916, and pigs 12 035

The following were the landowners in the county (exclusive of London) at the time of the Domesday survey —the king the archbishop of Canterbury the bishop and canons of London the abbeys of Westminster and Holy Trinity at Caen the nunnery of Barking, the Earls Roger and Morton, Geoffrey de Mannevele Ernulf de Hesding Walter Fitz Other Walter de St Walery Richard Fitz Gilbert Robert Gernon Robert Fafiton Robert Fitz Roselin, Robert Blund, Roger de Rames, William Fitz Ansculf Edmund de Salisbury Aubrey de Vere Ranulf Fitz Ilger Derman, Countess Judith and the king's almoners

In 1873 according to the *Return of Owners of Land* the total number of owners in the county (also exclusive of London) was 11,881 of whom 9006 owned less than an acre The extent of lands (including common or waste lands is given as 145 605 The gross estimated rental was £1 611 655 Sixteen owners each possessed over 1000 acres The crown owned 2382 acres (annual value £5503), the duchy of Lancaster 2273 acres (£4492 Ecclesiastical Commissioners, 1308 acres (£46 519) All Souls College, Oxford, 1818 acres (£4724) Christ Church Oxford 1132 acres (£1636), and King's College Cambridge 1097 (£1084)

Many villages of Middlesex, especially those near to London, were formerly famous for their mineral springs Some places are still supplied with water from wells, but the Barnet, the East Middlesex, the Grand Junction, the West Middlesex, and the New River Water Companies serve a large part of the county

Manufactures and Trade—There is little to remark with regard to the manufactures of the county outside of London Brick making and tile making have always flourished, and malting, distilling, and soap making are favourite industries. Gunpowder mills exist at Twickenham and Bedfont. The market towns for corn are Uxbridge, Brentford, and Staines, for cattle and sheep Southall A horse and cattle fair is held at South Mimms and Barnet

Railways and Roads—As London is the centre of the railway system of England, it is evident that many of the lines must run through Middlesex For similar reasons it is well provided with roads

Population—The total population of Middlesex was 2,539 765 in 1871 and 2 920 485 in 1881, or excluding the seven metropolitan boroughs lying within the county 276 028 in 1871 and 394,089 in 1881 Most of the towns and villages have largely increased during the period between 1871 and 1881 the populations of Acton and Tottenham have more than doubled, and Chiswick, Ealing, Edmonton and Willesden have almost doubled Of the larger places the least increase has been at Brentford which numbered 10 271 in 1871 and reached 11,808 in 1881 At the time of the Domesday survey the population of Middlesex, exclusive of London, was 2302

Government—Unlike other counties, Middlesex has no high sheriff appointed by the sovereign It is subject to the City of London and one of the sheriffs appointed by the lord mayor is sheriff for Middlesex When Henry I came to the throne he gave the city an extensive charter, and one of the privileges either granted or confirmed by the king was the perpetual sheriffwick of Middlesex

The whole of the county is included in the diocese of London, and is divided between the archdeaconries of London and Middlesex When Henry VIII created the bishopric of Westminster he allotted the whole county (the parish of Fulham alone excepted) for its diocese Edward VI, however, dissolved the bishopric in the fourth year of his reign

The county is divided into six hundreds, which remain the same as they were at the time of the Domesday survey, except that the name of one has been changed —Ossulston (Osulvestane D), Edmonton (Delmetone D), Gore (Gara D), Elthorne (Helctorne or Helethorne D), Spelthorne (Speletorne or Spelethorne D), Isleworth (Honeslaw D i e, Hounslow) The division into hundreds is now merely a name and a record of a former system of local government

There are thirty two poor law unions, but the unions beyond London are only eight in number, viz, Brentford, Edmonton, Fulham Hackney Hampstead, Hendon, Staines, Uxbridge

The majority of hospitals are in London but there is a training hospital at Tottenham St John's Hospital at Twickenham, and cottage hospitals at Enfield, Ealing Hayes, Hillingdon, Sudbury, and Teddington The Royal India Lunatic Asylum is at Ealing, and the two county asylums at Colney Hatch and Hanwell

The county is within the jurisdiction of the central criminal court and also of the metropolitan police (with the exception of the City)

Parliamentary Representation—There are nine constituencies in Middlesex, returning nineteen members viz, two for the county, four for the City of London, two for each of the boroughs of Westminster Finsbury Marylebone, the Tower Hamlets, Chelsea, and Hackney, with one for the university of London

In the parliament of 1295 Middlesex was represented by two members, in 1298 London sent two members as well as the county For the parliament of 1320 and subsequent parliaments London elected four members but it does not appear that all were allowed to sit From the 15th century however, the city has always sent four members to parliament In 1547 Westminster first sent her two members, and from that time until 1832 the only seats were those for the county and the two boroughs In 1832 the boroughs of Finsbury, Marylebone and Tower Hamlets were added, and in 1868 the boroughs of Chelsea and Hackney and the university of London

History—The district now included in Middlesex was largely occupied by forest up to a comparatively recent period, and its population must always have been very sparse A few prehistoric remains have been discovered at various times,—bones of the elephant, hippopotamus, deer, &c, at Old Brentford, elk horns near Chelsea Hospital, fossil teeth, fish, fruit, &c, at Highgate, and quite recently in 1879, while the foundations were being dug out for Drummond's New Bank at Charing Cross, a large number of prehistoric animal remains Flint instruments have also been found to cover a considerable area During the British period the district is supposed to have been inhabited by the Trinobantes, but the late Dr Guest affirms that the valley of the Lea was the western boundary of that tribe In answer to the question—What became of the district between the Lea and the Brent? this great authority states that the district was merely a march of the "Catuvellauni," a common through which ran a wide trackway, but in which was neither town, village, nor inhabited house Dr Guest also declares that the boundaries of the Catuvellaunian state, a central kingdom formed or much extended by Cassivellaunus, can be traced in part along the northern limit of Middlesex by following an earthwork called Grimesditch "from Brockley Hill to the woodland of the Colne Valley and thence to the Brent, and down the Brent to the Thames [1] Some earthworks and encampments still exist which are attributed to the Britons

When the country was under Roman rule great improvements, due to the growing importance of Londinium were made in this district Several roads in connexion with the city must have been constructed, more especially the great northern and eastern roads Dr Guest does not believe that the present Watling Street could have had any connexion with the Watling Street which came down the Edgeware Road passed along by Park Lane and crossed the Thames at Westminster In the Antonine Itinerary mention is made of three stations viz, Londinium, Sulloniacæ and Pontes Sulloniacæ is now Brockley Hill Pontes is supposed by Stukeley to mean Staines, but Horsley held that it was intended for Old Windsor, and others supported the claims of Colnbrook and Longford Roman camps have been found in many parts of the county, and Dr Stukeley supposed that the Brill near St Pancras was the site of the battle between Boadicea and the Roman legions which has left a slight record in the name of Battle Bridge The Roman remains found at different times are too numerous to mention here in detail Coins urns and tiles were found at Enfield a sepulchral urn at Hampstead, and numerous gold coins and ornaments at Bentley Priory Great Stanmore in 1781

Cowey Stakes about a furlong west of Walton Bridge is supposed to be the locality of the ford by which Julius Cæsar crossed the Thames Cæsar makes special mention of the sharp stakes which he had to encounter and Bede says that the remains of the stakes were to be seen in his day Camden was the first to fix upon this as the spot where Cæsar crossed and he is supported by Dr Guest but the identification is not undisputed Although a ford existed here as late as 1807 and stakes were found up to the end of the 18th century it has been affirmed that they were placed in their position with another object than to oppose an enemy's progress Roman remains have been found at Shepperton near Halliford at the Middlesex end of the ford A vase was dug up in 1817, and the remains of a Roman cemetery have also been discovered

As to the earliest Saxon occupation we are left very much to conjecture, and the name itself is somewhat of a puzzle It is evident that no tribe could have obtained the name of Middle Saxons until after the settlement of the districts on each side of it by the East and the West Saxons As Middlesex was for a period dependent upon the kingdom of Essex it is probable that the name did not come into use until London had become a Saxon city although there is reason to believe that previously Saxon settlements had been made on several places by the river and elsewhere Bede tells us that London was in the hands of king Sæberct in 604 and was then the chief town of Essex Just a century afterwards—that is in 704—the king of the East Saxons granted away land at Twickenham, showing that Middlesex was then dependent upon Essex It is worthy of note that the two districts now forming the counties in which London and Southwark are situated were separated from the kingdoms to which they originally belonged probably on account of the importance of the city of London and the borough of Southwark Middlesex from the kingdom of Essex and Surrey or the South Ridge (A S Suð rige) from the kingdom of Kent

Middlesex appears never to have been independent The administrative shire was let to the men of London and their heirs to be held in farm of the king and his heirs and 'the subject shire has to submit to the authority of the sheriffs chosen by the ruling city [2]

Middlesex is only once mentioned in the Saxon Chronicle, under date 1011, where it is noticed as one of the districts overrun by the Danes One manuscript (A Winchester) mentions the Middle Saxons as receiving the true faith under their alderman Peada in 653, but this is evidently a mistake of the scribe, for the fact is taken from Bede, and he writes Middle Angles, as do the other MSS of the Chronicle [3]

The Saxons appear to have settled over a large portion of the district, and for the purpose of settlement they must have made considerable clearings in the vast forest of Middlesex There seems to be good reason for believing that previous to their coming the roads passed through waste lands By the time of Edward the Confessor a large proportion of the present towns and villages were in existence Mr Elton in his *Origins of English History*,[4] mentions a curious fact with relation to the tenures which prevailed in some of these places He alludes to a ring of manors encircling ancient London where the custom of Borough English or junior right was prevalent [5] He then goes on to point out that in this cluster of manors there are several varieties of the custom —'Its benefit in Islington and Edmonton was confined to the youngest son, at Ealing Acton, and Isleworth it extended to the brothers and male collateral heirs, and in a great number of instances the privilege was given to females as well as to males in every degree of relationship These variations are of no very great importance the custom being modified in all parts of the country by the rule that special proof must be given of any extension of that strict form of Borough English for the benefit of the younger son of which alone the courts have cognizance But it is of the greater interest to observe that in several places near London it is the custom for the land to descend to the youngest if it is under a particular value of five pounds, but if it is worth more, it is parted among all the sons (*First Real Property Commission Evidence* p 254)

The great forest of Middlesex continued long after the Norman Conquest and even as late as the reign of Elizabeth portions of it still existed quite close to London Fitz Stephen the monk of Canterbury and secretary of Thomas a Becket mentions in his interesting description of London the immense forest with its densely wooded thickets and its coverts of game stags fallow deer boars and wild bulls A few years after Fitz Stephen's death, in the reign of Henry III (1218) the forest was disafforested and some of the wealthy citizens took the opportunity of purchasing land and building upon it Matthew Paris in his life of the twelfth abbot of St Albans describes the woods contiguous to the Watling Street between London and St Albans as almost impenetrable, and so much infested by outlaws and by beasts of prey that the numerous pilgrims who travelled along the Roman road to the shrine of Albanus were exposed to imminent danger

There is little further history that can be told of Middlesex There are many interesting incidents connected with some of the places but corporate life has been crushed out of the county by the greatness of London Not a single place except London has grown into importance and nowhere outside of London is there a building of first rate interest The villages on the Thames early began to increase in size on account of the convenience of locomotion supplied by the river It is only since the extension of the railway system that the villages to the north and north west of London have grown in size and this growth has been mainly due to the building of houses for the use of the Londoners

Bibliography—John Norden *Speculum Britanniæ the first parte an historicall and chorographicall discription of Middlesex* 4to London 1593 reprinted in 1637 and 17 3 John Bowack *The Antiquities of Middlesex* parts 1 and 2 folio London 1705 6 Ric Newcourt *Repertorium Ecclesiasticum Parochiale Londinense* 2 vols folio London 1708 Rev Thomas Cox *Magna Britannia et Hibernia antiqua et nova* 6 vols 4to London 1 20 (vol iii contains Middlesex) *A Description of the County of Middlesex* 8vo London 1775 Rev Daniel Lysons *The Environs of London* 4 vols 4to London 1 92 96 (vols ii iii and supplement 1811 contain Middlesex) John Middleton *General View of the Agriculture of Middlesex* 4to London 1 93 Peter Foot *General View of the Agriculture of Middlesex* 4to London 1 94 John Middleton *View of the Agriculture of Middlesex* 8vo London 1798 second edition 1807 Rev D Lysons *An Historical Account of those Parishes in the County of Middlesex which are not described in The Environs of London* 4to London 1800 G A Cooke *Modern British Traveller* 12mo London, 1802 10 (vol xi contains Middlesex) E W Brayley Rev Joseph Nightingale and J Norris Brewer London and Middlesex in *Beauties of England and Wales* 5 vols 8vo London 1810–16 Rev William Bawdwen *A Translation of the Record called Domesday so far as relates to the Counties of Middlesex Hertford Buckingham Oxford and Gloucester* 4to Doncaster 1812 other publications concerning the Domesday of Middlesex are facsimile folio Southampton 1861 a literal extension of the Latin text, folio London 1862 Wm Ryley and Hy Dethick *The Visitation of Middlesex begun in 1663* folio Salisbury 18 0 William Pinnock *The History and Topography of Middlesex* 12mo London 1824 (vol 3 of Pinnock's *County Histories*) W Smith *Delineations of the County of Middlesex* 8vo London 1834 Samuel Tymms *A Compendious Account of Middlesex and London and Westminster* (Camden's *Britannia* epitomized and continued vol vii) London 1843 J H Sperling *Church Walks in Middlesex being an Ecclesiologist's Guide to that County* 12mo London 1849 *The Beauties of Middlesex being a particular description of the principal seats of the nobility and gentry in the County of Middlesex* 8vo Chelsea 1850 *The Counties of England* (No 1 Middlesex) 8vo London 1855 *Transactions of the London and Middlesex Archæological Society* 8vo 1860–82 James E Harting *The Birds of Middlesex* 8vo London 1866 Henry Trimen and W T Thiselton Dyer *Flora of Middlesex* 8vo London 1869 William Hughes *The Geography of Middlesex for the use of schools* 12mo London 1872 William Lawson *Collins's County Geographies* (Middlesex) 8vo 18 2 *The Geography of the Counties of England and Wales* (No 10 Middlesex 8vo Manchester 1872 W E Baxter *The Domesday Book for the County of Middlesex, being that portion of a Return of Owners of Land in England and Wales in 1873 which refers to Middlesex* 4to Lewes 1877 (H B W *)

---

[1] Lecture on the Origin of London *Athenæum* 1866 No 2022

[2] Freeman *Norman Conquest* vol v (1876) p 468

[3] In the above passage from the Chronicle where the districts overrun by the Danes in 1011 are enumerated the shires which took their names from their chief towns are distinctly marked off from the districts which took their names from the peoples who inhabited them Of the latter there are besides the Middle Saxons, the East Angles the Kentings and the South Saxons Middlesex is styled an administrative shire because it was not historically a shire but only one for the purposes of administrative organization Of the present forty counties twenty eight are and twelve are not shires Wessex was divided into six shires, and Mercia into eighteen with the subsequent addition of Rutland taken [illegible] Cumbria and last of all Monmouthshire from Wales, by an Act of Henry VIII s reign

[4] Pp 188–89 and note

[5] Mr Corner gives the number of instances he has found at sixteen

MIDDLETON, a market and manufacturing town of Lancashire, is situated on the Irk, near the Rochdale Canal, and on the Lancashire and Yorkshire Railway, about 5 miles north of Manchester and 4 west of Oldham. It includes the township of Tonge, an isolated portion of the parish of Prestwich. The church of St Leonards is an old structure of mixed architecture, with a low square tower. The oldest portion of the building dates from the 12th century, but the main portion from 1412, and the south aisle from 1524. It underwent extensive restoration in 1869. The Queen Elizabeth Grammar School, a building in the Tudor style, was founded in 1572. There are public baths and a free library. The prosperity of the town dates from the introduction of manufactures at the close of last century. The staple trade is the spinning and weaving of cotton and the other industries include silk weaving, calico printing, bleaching, dyeing, ironfounding, and the manufacture of soap and chemicals. There are several collieries in the neighbourhood. The town was at an early period in possession of the Bartons, from whom it passed by marriage in the 16th century to Sir Ralph de Assheton. The population of the urban sanitary district of Middleton and Tonge in 1881 was 18,952.

MIDDLETON, CONYERS (1683–1750), the earliest and most eminent example of the spirit of theological rationalism in the English Church of the 18th century, was the son of the rector of Hinderwell near Whitby, and was born at Richmond in Yorkshire, on December 27 (or, according to another account, on August 3), 1683. He graduated at Cambridge, took orders, and in 1706 obtained a fellowship, which he soon resigned upon contracting an advantageous marriage. In 1717 a dispute with Bentley, upon an extortionate demand of the latter on occasion of Middleton's being created D.D., involved him in an acrimonious controversy, which called forth several pamphlets from his pen full of powerful invective, and among them his first considerable literary performances, the *Remarks* and *Further Remarks* on Bentley's *Proposals for a New Edition of the Greek Testament* (1721). "You have laid Bentley flat upon his back," wrote Colbatch. "I scorn to read what the rascal has written," wrote Bentley,—who, however, only resorted to this affected disdain after a fruitless attempt to fix the authorship upon Colbatch, but who might justly have commented upon the impropriety of Middleton's endeavour to visit his grievances upon the text of the New Testament. Private resentment and uncurbed personality were throughout his life too frequently the motive and the note of Middleton's controversial publications. In 1723 he was involved in a lawsuit by personalities against Bentley, which had found their way into his otherwise judicious tract on library administration, written on occasion of his appointment to the honourable office of university librarian. In 1726 he gave great offence to the medical profession by a dissertation contending that the healing art among the ancients was only exercised by slaves or freedmen. Between the dates of these publications he visited Italy, and made those observations on the pagan pedigree of Italian superstitions which he subsequently embodied in his *Letter from Rome* (1729). This cogent tract, while establishing the author's main proposition with abundant learning and wit, gave at the same time the first clear indication of the anti-supernaturalistic bias of his intellect, and probably contributed to prepare the storm which broke out against him on his next publication (1731). In his remonstrance with Waterland on occasion of the latter's reply to Tindal's *Christianity as Old as the Creation*, Middleton takes a line which in his day could hardly fail to expose him to the reproach of infidelity. He gives up the literal truth of the primeval Mosaic narratives, and, in professing to indicate a short and easy method of confuting Tindal, lays principal stress on the indispensableness of Christianity as a mainstay of social order. This was to resign nearly everything that divines of the Waterland stamp thought worth defending. Middleton was warmly assailed from many quarters, and retreated with some difficulty under cover of a sheaf of apologetic pamphlets, and a more regular attendance at church. A freethinker in the strict sense of the term he certainly was; but how far freedom of thought was carried by him it is not easy to ascertain. His adversaries—some of them men who gravely maintained that Egyptian civilization originated in the age of Solomon—were unable to fix any serious imputation upon him; on the other hand it is clear that the natural attitude of his mind towards supernatural pretensions was one of suspicion, and that his temperament was by no means devout. That he was nevertheless not incapable of a disinterested hero-worship was evinced by his next important publication, the elegant but partial *Life of Cicero* (1741), a work which, if far below the standard of modern exactness, may yet compare in spirit and execution with the best productions of the Italian Renaissance. It is, indeed, as remarked by Forsyth, "rather an historical composition, in which Cicero is the principal figure, than the portrait of the man himself"; and Dr Parr has pointed out Middleton's unacknowledged obligations to the forgotten Bellendenus, which, however, with the ardour of a discoverer, he seems to have considerably overrated. The work was undertaken at the instance of Lord Hervey, in correspondence with whom also originated his disquisition on *The Roman Senate*, published in 1747. The same year and the following produced the most important of all his writings, the *Introductory Discourse* and the *Free Inquiry* concerning the miraculous powers then commonly deemed to have subsisted in the church after the apostolic age. In combating this belief Middleton indirectly established two propositions of capital importance. He showed that ecclesiastical miracles must be accepted or rejected in the mass; and he distinguished between the authority due to the early fathers' testimony to the beliefs and practices of their times and their very slender credibility as witnesses to matters of fact. Some individual grudge seems to have prompted him to expose, in 1750, Bishop Sherlock's eccentric notions of antediluvian prophecy, which had then been before the world for a quarter of a century. The same year he died of a decline at his seat at Hildesham in Cambridgeshire, leaving a widow, but no children.

Middleton's most ambitious work is obsolete from no fault of his, but his controversial writings retain a permanent place in the history of opinion. In his more restricted sphere he may not inappropriately be compared to Lessing. Like Lessing's, the character of his intellect was captious and iconoclastic, but redeemed from mere negation by a passion for abstract truth too apt to slumber until called into activity by some merely personal stimulus. His diction is generally masculine and harmonious. Pope thought him and Hooke the only prose writers of the day who deserved to be cited as authorities on the language. Parr, while exposing his plagiarisms, heaps encomiums on his style. But his best qualities, his impatience of superstition and disdain of mere external authority, are rather moral than literary. As a scholar he is rather elegant than profound; as a controversialist he has more vigour than urbanity, and more wit than humour. He has been unjustly attacked both as author and as man by De Quincey, who strangely accuses his style of colloquialism, and taxes him with eating the church's bread while denying her doctrines. In fact Middleton's private means were ample, his ecclesiastical emoluments trifling, and his candour obstructed his path to much more considerable preferment. The best general view of his intellectual character and influence is to be found in Leslie Stephen's *English Thought in the Eighteenth Century*, chap. vi. A handsome edition of his works, containing several posthumous tracts, but not including the *Life of Cicero*, appeared in 1752.

MIDDLETON, THOMAS (c. 1570–1627), held a leading place among the dramatists of the reign of James I. His popularity would seem to have first come to a height about 1607. This is a fair inference from the fact that in this and the following year a whole swarm of comedies from his pen were licensed and published—*A Trick to Catch the Old One*, *The Family of Love*, *The Phœnix*, *Michaelmas Term*, *Your Five Gallants*, *A Mad World My Masters*. Only the first of these kept the stage after the author's own generation, though in point of wit and constructive skill it is not superior to *The Phœnix* (a serious comedy) or *Your Five Gallants* (a bustling and gaily humorous farcical comedy). The plot of the *Trick* bears a family likeness to that of Massinger's *New Way to Pay Old Debts*, the titles in fact might be interchanged. A ruined scapegrace outwits his creditors and a usurious uncle by coming to town with a courtesan and passing her off as a widow with a fortune, whom he treats with deferential friendship, but hardly dares to love, ruined and hopeless as he is. His uncle lends him money that he may woo in proper state; his creditors also intrigue to have the honour of supplying him with all the needs of fashion; and the lady receives many costly presents from aspirants to her hand and fortune. Though Middleton was apparently not in high popularity till 1607, he had made his debut as a satirist ten years before; and if Malone is right in his conjecture that the *Mayor of Queensborough* is identical with the *Randall Earle of Chester* mentioned by Henslowe in 1602, he had done dramatic work of a much higher kind. Like *The Changeling*, a later production, in which Middleton had the assistance of Rowley, the tragedy of the *Mayor* is named after a character in the insignificant comic underplot. Such a title scares away readers weary of half intelligible Elizabethan fun and satire; but Simon the comic mayor is a very subordinate figure in the play, and the tragic portions alike in situation, characterization, and language rank among the very noblest productions of the Shakespearian age. There are scenes in the *Changeling* also which Mr Swinburne, with a judgment that will not be disputed, assigns to Middleton, unsurpassed for intensity of passion and appalling surprises in the whole range of Elizabethan literature. The execution of these scenes is far beyond any power that Rowley showed in single handed work, but well within the scope of the author of the *Mayor of Queensborough* and *Women Beware Women*. This last play, in which every one of the characters important enough to be honoured with a name perishes at the end in a slaughter so rapid as to be somewhat confusing, was apparently one of Middleton's later works, and the simple and measured development of the plot in the first acts seems to show traces of the influence of Massinger. Middleton's verse, when charged with the expression of impassioned love, contains many echoes of the verse of *Romeo and Juliet*, as if his ear had been fascinated by it in his youth. His language generally proclaims him an admiring disciple of Shakespeare's; and in daring and happy concentration of imagery, and a certain imperial confidence in the use of words, he of all the dramatists of that time is the disciple that comes nearest the master. *The Witch*, by which Middleton's name has of late been linked with Shakespeare's in groundless speculation as being part author of *Macbeth*, is by no means one of Middleton's best plays. The plot is both intricate and feeble, as if the play had been written with a view to the half comic spectacular exhibition of the witches, with their ribald revelry, their cauldrons, hideous spells, and weird incantations. Charles Lamb's comparison of Middleton's witches with Shakespeare's is one of the most exquisite morsels of criticism; but, when he says that Middleton's witches are "in a lesser degree fine creations," he ought perhaps to have added that they are merely embodiments of the vulgar superstition, put on the stage to excite laughter rather than fear among a half believing audience, an audience ready to laugh at them in the light and in a crowded meeting, whatever each might do in the dark alone. That Middleton had any share in *Macbeth* is a conjecture resting solely on the fact that the opening words of the song of the witches about the cauldron in Shakespeare's *Macbeth* occur also in the incantations about a cauldron in the last act of Middleton's *Witch*, and that Middleton's song was inserted by Davenant in an "amended" reproduction of *Macbeth*. If either borrowed the words of this song from the other, that is no evidence of further co operation; besides all that is common to the two was probably as much public property as a nursery rhyme. There is no evidence as to whether *The Witch* appeared before or after *Macbeth*. Middleton co operated with Dekker in the *Roaring Girl*; with Rowley in *A Fair Quarrel*, *The Spanish Gipsy*, and *The Changeling*; and with Jonson and Fletcher in *The Widow* (one of the few of Middleton's plays reproduced after the Restoration). Towards the close of his life Middleton got into difficulties with the privy council from writing a very clever political play apropos of Prince Charles's unsuccessful wooing of the Spanish infanta in 1623. The chief personages in Spanish politics and their manœuvres were represented with most ingenious skill in the pieces and movements of *A Game at Chess*. This play was stopped by royal authority, and the prosecution of the author was allowed quietly to drop. The few unimportant facts known in Middleton's private history are collected in Mr Dyce's admirable edition of his plays. He enjoyed the office of city chronologer, and was often employed to write pageants and masques, in one case at least contracting for the whole exhibition, besides furnishing the words. He died in 1627, and was buried at Newington Butts.

MIDDLETOWN, a city and port of entry of the United States, and one of the shire towns of Middlesex county, Connecticut, lies on the right bank of the Connecticut river, about 30 miles from its mouth, directly opposite the well known Portland quarries, and 24 miles from New Haven by rail. Built on ground rising gently from the river, with its principal streets keeping the direction of the valley, and the cross streets climbing the slope, Middletown is a place of considerable attractiveness, and the views from the higher points are particularly fine. Water Street, with the wharves and shipping, Main Street, with the commercial houses and hotels, and High Street, with its mansions and gardens and trees, are the leading lines of the city. On the high grounds behind stand the handsome buildings of the Wesleyan (Methodist Episcopal) University. The institution, mainly organized by Wilbur Fisk, D.D., was chartered in 1831. To the two buildings with which it started have been added Rich Hall, with the library of about 30,000 volumes, Judd Hall, with scientific collections of great value, the Memorial Chapel, erected in the centenary year of American Methodism, and the Observatory Hall. Since 1872 the courses of the university have been open to both sexes. In 1882 the number of professors was 20, and of students 191, including 14 females. The Berkeley Theological School (Main Street), founded by the Episcopal Church in 1854, had in 1882 7 professors and 41 students, with a library of 17,000 volumes. A hill 1¼ miles to the south east of the city is occupied by the State General Hospital for the Insane, the principal building having a frontage of 768 feet, and the grounds extending to 230 acres; and on another hill to the south west of the city stands the State industrial school for girls. As vessels drawing 10 feet of water can reach its wharves, Middletown carries on a considerable trade by the river. In 1882 1613 vessels, with a burden of 240,000 tons, entered the port, and 1613 vessels, with a burden of 350,000 tons, cleared, and the Middletown district owned 83 sailing vessels and 22 steamers Both the silver and the lead mines which were formerly worked in the vicinity have been abandoned, but cast iron, britannia, and silver plated goods, sewing machines, pumps, webbing, and tape are among the local manufactures The population of the city increased from 5182 in 1860 to 6850 in 1880 First settled in 1636, Middletown was incorporated as a town in 1654, and as a city in 1784

MIDDLETOWN, a manufacturing village of the United States, in Wallkill township Orange county, New York, 55 miles N N W of New York, at the junction of four railroads It is a clean well built place, in the midst of a fine dairy farming and stock raising district, manufactures saws files, felt hats, blankets, agricultural implements, printers materials, &c, and is the seat of the State Homœopathic Insane Asylum The population was 6049 in 1870 and 8494 in 1880

MIDHURST, an ancient parliamentary borough and market town of Sussex, is picturesquely situated on a gentle eminence above the south bank of the West Rother, on three railway lines, 50 miles south west of London and 12 north from Chichester The church of St Denis (restored in 1881-83) is chiefly Perpendicular in style, but the lower part of the embattled tower is probably Norman At the grammar school, founded in 1672, Richard Cobden and Sir Charles Lyell were educated A new public hall was opened in 1882 The old castle of the De Bohuns stood on a mound above the river, now overgrown with trees In ancient times a commandery of the Knights of St John of Jerusalem had jurisdiction over the district now forming the liberty of St John The prosperity of the town depends chiefly on agriculture A market is held weekly, and a fair three times a year The population of the parliamentary borough, which has an area of 26,172 acres, was 6753 in 1871, and 7221 in 1881

Midhurst is not mentioned in Domesday being included under Easebourne In the reign of Henry I it was held by the king as a minor barony In the time of Edward I it passed into the possession of the De Bohuns From the time of Edward II till 1832 it returned two members to parliament, but since then only one

MIDIAN was one of the peoples of North Arabia whom the Hebrews recognized as distant kinsmen, representing them as sons of Abraham s wife Keturah The word Keturah means "incense , thus the sons of Keturah are the "incense men,' not indeed inhabitants of the far south incense land, but presumably the tribes whose caravans brought the incense to Palestine and the Mediterranean ports So the Midianites appear in connexion with the gold and incense trade from Yemen (Isa lx 6), and with the trade between Egypt and Syria (Gen xxxvii 28, 36) At the time of the exodus the pastures of the Midianites, or of the branch of Midian to which Moses s father in law (Jethro or Raguel, or Hobab) belonged, lay near Mount Horeb (Exod iii 1), and Num x 29 *sq* implies that the tribe was at home in the desert of the wanderings The Kenites, who, in spite of their connexion with Amalek (1 Sam xv 6), had friendly relations with Israel, and ultimately coalesced with the tribe of Judah, are represented in Judg i 16, iv 11 as the kin of Moses s father in law The Kenites, however, can have been but one fraction of Midian which took a separate course from their early relations to Israel[1] The main body appear in Judg vi as a powerful Bedouin confederation, invading Canaan from the eastern desert, and ravaging the land as similar tribes have done in all ages when Palestine lacked a strong government With their defeat by Gideon and another defeat by the Edomites in the field of Moab, probably about the same time (Gen xxxvi 35), the recorded history of Midian closes

A place Midian is mentioned 1 Kings xi 18, and in later times the name lingered in the district east of the Gulf of Akaba, where Eusebius knows a city Madian in the country of the Saracens and Ptolemy places Modiana Still later Madyan was a station on the pilgrim route from Egypt to Mecca, the second beyond Aila (Elath) Here in the Middle Ages was shown the well from which Moses watered the flocks of Sho aib (Jethro) and the place is still known as the caves of Sho'aib It has considerable ruins which have been described by Ruppell (*Reisen* 1829) and Burton (*Land of Midian* 1879)

MIDNAPUR, a district in the lieutenant governorship of Bengal, India, between 21° 37 and 22° 57 N lat, and between 86° 35 45 and 88° 14 E long, is bounded on the N by Bánkurá and Bardwán, on the E by Hooghly and Howrah, on the S by the Bay of Bengal, and on the W by Singbhum and Mánbhum, with an area of 5082 square miles Its general appearance is that of a large open plain, of which the greater part is under cultivation In the northern portion the soil is poor, and there is little wood The country along the western boundary, known as the Jungle Mahâls, is undulating and picturesque, it is almost uninhabited The eastern and south eastern portions are swampy and richly cultivated The chief rivers of the district are the Hooghly and its three tributaries, the Rupnáráyan, the Haldi, and the Rasulpur The Midnapur high level canal runs almost due east and west from the town of Midnapur to Ulubariá on the Hooghly 16 miles below Calcutta, and affords a continuous navigable channel 53 miles in length There is also a tidal canal for navigation, 26 miles in length, extending from the Rupnáráyan river The jungles in the west of the district yield lac, *tasar* silk, wax, resin, firewood, charcoal, &c, and give shelter to large and small game

The census of 1872 returned the population of Midnapur at 2 540 963 (1 257,194 males and 1,283 769 females) including only 122 Europeans and 157 030 Mohammedans The aboriginal tribes belong chiefly to the jungles and hills of Chutia Nagpur and Bankura the most numerous of them are Santals (96 921) and Bhumijs (35 344) Of high caste Hindus the returns show 136 500 and the number of Kayasths is given as 101 663 Among the semi Hinduized aborigines the most numerous are the Bagdis, a tribe of cultivators, fishermen and day labourers (76 825) Belonging to agricultural castes there are 1,018 686 The four municipalities are Midnapur (31 491), Chandrakona (21,311), Ghatal (15 492) and Tamluk (5849) Rice is the staple crop Irrigation is effected chiefly from the high level canal Rent rates vary from 10½d an acre for the poorest quality of rice land to 18s an acre for the best irrigable lands The district suffers occasionally from drought, floods are common, and very disastrous in their results The principal exports are rice, silk, and sugar and the chief imports consist of cotton cloth and twist Salt, indigo silk, mats, and brass and copper utensils are manufactured Apart from the rivers, communication is afforded by 482 miles of road The total revenue in 1870 71 was £262 578, and the expenditure £53 777 The prevailing diseases are fever, diarrhœa, dysentery, and cholera The average mean temperature is 80° Fahr, and the average annual rainfall 66 inches

The early history of Midnapur centres round the ancient town of Tamluk, which in the beginning of the 5th century was an important Buddhist settlement and maritime harbour The first connexion of the English with the district dates from 1760, when Mir Kasim ceded to the East India Company Midnapur, Chittagong, and Bardwan (then estimated to furnish one third of the entire revenue of Bengal) as the price of his elevation to the throne of Bengal on the deposition of Mir Jafar

MIDNAPUR, chief town and headquarters station of the above district, is situated on the north bank of the Kasái river, with a population in 1872 of 31,491 The town has a large *bázár*, with commodious public offices It is healthy, dry, and well supplied with water An American mission maintains an excellent training school, together with a printing press, and has founded several village schools in the district. Its efforts have been particularly successful among the Santáls, and some of the earliest and most valuable works on their language have issued from the Midnapur mission press. A brisk manufacture of brass and copper utensils takes place in the town, it is also the centre of a large indigo and silk industry

---

[1] The admixture of Midianite elements in Judah and the other border tribes of Israel is confirmed by a comparison of the names of the Midianite clans in Gen xxv 4 with the Hebrew genealogies (1 Chron ii. 46, iv 17. v 24 Gen xlvi 9)

MIDRASH Like all nouns of a similar form *Midrash* is the equivalent of the Niph'al participle,[1] and as such yields as many modified meanings as the root *Darosh* (דרש), to search, &c, itself has The practical significations, however, of *Midrash*, taken in historical order, are as follows —(1) a book of records, (2) a recension of older, especially historical, materials, (3) search in and explanation of the Scriptures, notably the Pentateuch (in which case the plural is invariably *Midrashoth*), (4) theory as distinguished from practice, (5) a college for study and teaching, (6) an *Agadic* (that is, a free) explanation, in contradistinction to an *Halakhic* one, (7) a collection of such free explanations (in which case the plural is *Midrashim* and occasionally also *Midrashoth*) Of these seven significations (1) and (2) are to be found in the Bible,[2] (3) and (4) are mentioned for the first time in the *Mishnah*,[3] (5) is to be met with in the *Midrash*,[4] while (6) and (7) are to be found in early Rabbinic writings[5]

The subject of this article will be—(1) the nature of *Midrash* in the sense of *Agadah*, to the exclusion of *Halakhah* (for which see MISHNAH), and (2) the development of this *Midrash Agadah* into books (*Midrashim*)

The thinking reader of the Scriptures cannot have failed to observe that by the side of their ceremonial element, be it negative or affirmative, permissive or jussive, there is also often to be met with (and sometimes so as to be inseparable from it) a spiritual element This spiritual element rests chiefly on feeling or emotion, and produces pious works only indirectly Now the explanation or application of this element, either by the Scriptures themselves or by the rabbis, is traditionally called *Midrash Haggadah* (recitation, preaching) or *Midrash Agadah*[6] (binding the soul to God and all that is godly)

This *Haggadah* or *Agadah* varies considerably both in nature and form In its nature it sometimes humours, at other times threatens, it alternately promises and admonishes, persuades and rebukes, encourages and deters In the end it always consoles, and throughout it instructs and elevates In form it is legendary, historical, exegetic, didactic, theosophic, epigrammatic, but throughout it is ethical

And varied as was and is the *Midrash Agadah*, so varied have been its fortunes Whilst at times it stood very high in the estimation both of the teachers and the congregations in Israel,[7] it sank at other times very low indeed[8] Nay, at one and the same time, whilst some rabbis exalted it to the skies,[9] other rabbis treated it with hatred,[10] or, worse still, with contempt[11] There have actually been teachers whose treatment of it differed with the difference of the occasion.[12] The fact is the Jews liked or disliked the *Midrash Agadah* according to their political condition on the one hand and their proximity to Jewish professors of Christianity on the other In the hour of prosperity the Jews preferred the *Halakhah*,[13] in that of adversity they ran to hear the consoling words of the *Agadah*[14] When near Judæo-Christians, whose religious strength and argument chiefly rested on *Agadah*,[15] the Jews disliked it, when among themselves, or when dwelling among Gentiles (heathen or Christian), they showed their wonted partiality for it

But, whatever were the likings or dislikings of the Jews for the *Midrashoth*, it is certain that these traditions were early[16] committed to writing, and formed into special volumes, known as "Books of *Agadah*"[17] Such were first some of the *Targumim* and then the *Midrashim* Against writing down the traditional explanations of the Mosaic ceremonial there existed a distinct law,[18] which was observed down to near the end of the 6th century At an earlier period isolated disciples only, in order to refresh their memory, wrote down short Halakhic notes, which, however, they kept in secret[19] The *Targumim* and *Midrashim*, on the other hand, were composed very early and were numerous, while their extensive contents were circulated in public

The *Midrash*, from whatever point of view it may be regarded, is of the highest value It is of the highest value, of course, to the Jew as Jew first, inasmuch as he finds there recorded the noblest ideas, sayings, and teachings of his venerable sages of early times In the next place it has value to the Christian as Christian, since only by these ideas, teachings, reasonings, and descriptions can the beautiful sayings of the Founder of Christianity, the reasonings of the apostles, and the imagery of the sublime but enigmatic Apocalypse be rightly understood But its importance appeals also to the general scholar, because of the inexhaustible mines of information of all kinds it contains The philologist will find here numerous hints on lexicography and grammar, chiefly, of course, of the Semitic languages, but also of other tongues, notably Greek and Latin The historian will gather here a rich harvest on geography, chorography, topography, chronology, numismatics, &c The philosopher will find here abundant and valuable notices on logic, psychology, metaphysics, theology, theosophy, æsthetics, rhetoric, poetry, mathematics, geometry, astronomy, zoology, botany, biology, morphology, chemistry, medicine, physics, &c The statesman—particularly if he be inclined to follow the Psalmist's advice—"from the ancients I gather understanding" (cxix 100)—will find here valuable information on ancient ethnography in the full sense of the term—politics, political economy, law, military science, naval affairs, &c The true scholar will find out by the study of the *Agadah* that many a discovery thought to belong to a recent age was well known to these ancient doctors

---

[1] Comp Nehem viii 8, where במקרא evidently stands for בנקרא See also Kimhi on 2 Chron xiii 22, and Schiller Szinessy, *Exposition*, &c, Cambridge, 1882, p 11

[2] 2 Chron xiii 22 and xxiv 27

[3] See *Nedarim*, iv 3, and *Aboth*, i 17

[4] *Bereshith Rabbah*, c lxiii (on Gen xxv 22) והלא לא הלכה אלא למדרשו של (שם ו)עבר *Midrash* is used in the East to this day for *Beth Hammidrash* See MS Oo 6, 63 (of the University Library, Cambridge), leaf 135*a*, lower margin (והם קדש למדרשו של שם)

[5] Rashi (*e g*, on Gen iii 8) and *Tosaphoth*, *passim*

[6] Those who identify this word as merely the Chaldaic form of the Hebrew *Haggadah* (and they have certainly some authority on their side) ought to write it *Aggadah* (אַגָּדָה), which, however, is not the traditional spelling of it (אֲגָדָה) Singularly enough, the Latin *religio* is similarly derived by some from *religare* and by others from *relegere*

[7] *Siphere* on Deut § 49 "If thou wishest to know Him who but spake and the world came into being, learn *Haggadah*, for by so doing thou wilt recognize the Holy One (blessed be He!) and cling to His ways!"

[8] T Y, *Maaseroth*, iii 4 "And R Zeerah was teasing those rabbis of the *Agadah*"

[9] *Ibid* "Then said to him R Bo bar [son of] Kohano, Why dost thou tease them? Ask, and they will surely answer thee!'

[10] T Y, *Shabbath*, xvi 1 "He who holds it forth becomes burned by it he who listens to it gets no reward'

[11] *Ibid* "I never in my life looked into Agadic books"

[12] *Ibid* "Let the hand of him who wrote it be cut off, and compare with this T B, *Bobo Bathro*, 123*b* "goodly pearl'

[13] Beginning of *Pesiktho Bahodesh Hasshelishi* "First when the money was at hand one desired to hear the word of the *Mishnah* and the word of the *Talmud*

[14] *Ibid* "Now, however, when the money is not to be got, and, moreover, when we are sick in consequence of the (treatment by the) government, one pines for the word of the Bible and for the word of the *Agadah*'

[15] T Y *Shabbath*, xvi 1, and T B, *Shabbath*, 116*a* "The *Evangelia* and other Christian writings"

[16] See *Tosephto Shabbath*, xiv "I remember that one brought before Rabban Gamliel the elder [St Paul's teacher] the book of Job (in the) Chaldaic paraphrase', and T Y, *Kilayim*, ix 4 "At that time I ran (my) eyes through the whole Book of the Psalms (in the form) of the *Haggadah* [*Agadah* of the Psalms]' R Hiyya *Rubboh* belonged to the middle of the 2d Christian century

[17] ספרי דאגדתא See T B, *Berakhoth*, 23*a*, *Temurah*, 14*b*, and the *Talmudim*, *passim*

[18] T B, *Gittin*, 60*b* "In the college of R Yishmael it was taught, 'These [see Exod xxxiv 27] thou oughtest to write down, but thou must not write down *Halakhoth*''

[19] T B, *Shabbath*, 6*b* "I found a 'secret roll,'" that is, a roll of *Halakhoth* kept secret. Comp Rashi, *in loco.*

The sources of the *Agadah* are five —(1) the *Targumim* and especially those on the Prophets and Hagiographa, (2) the non canonical *Mishnah* (*Mathnitho Boraitho*, see MISHNAH), which contains many valuable pieces, the age of which is often anterior, in essence if not in form, not only to those contained in the canonical *Mishnah*, but also to the sayings of the New Testament, (3) the canonical (officially recognized) *Mishnah*, which contains several entire treatises of an *Agadic* nature, as *Aboth*,[1] *Middoth*, &c,[2] and numerous pieces scattered here and there among the *Halakhah*, (4) both *Talmudim*[3] (the Palestinian and Babylonian), which have thousands of Agadic notices interspersed in their *Halakhoth*, and (5) the *Midrashim*, κατ' ἐξοχην It is of the last alone, as represented by their principal collections, that we give an historical enumeration here —

(1) *Megillath Taanith* is an historical *Midrash* consisting of twelve *Perakim*, and is called so on the principle of *lucus a non lucendo* seeing that in it are enumerated the days of the year on which a Jew must not fast The Aramaic part of it alone constitutes the real *Megillah*, and belongs to the beginning of the 2d Christian century[4] The *editio princeps* came out at Mantua, 1513, 4to but cheap editions have been printed at Warsaw and elsewhere

(2) *Sepher Yezirah* is a philosophico cabbalistic *Midrash* divided into six *Perakim*, which, in their turn are subdivided into *Mishniyyoth* It is variously ascribed to the patriarch Abraham and to R Akibah the illustrious teacher who suffered martyrdom under Hadrian To this rabbi the book, no doubt belongs both in substance and form[5] It has gone through numerous editions the *ed princ* being of 1562 (Mantua 4to) and has been translated into Latin, German and English (New York, 1877)

(3) *Othiyyoth de Rabbi Akibah* is a *quasi* cabbalistic *Midrash* on the alphabet belonging in essence if not in form, to the aforesaid teacher and martyr *Ed princ*, Constantinople 1520, 4to

(4) *Massekheth Hekhaloth* is an astronomico cabbalistic *Midrash* in seven *Perakim* It is ascribed to R Yishmael the high priest Judging from internal evidence on the one hand, and from what is known of R Yishmael in the *Talmudim* and *Midrashim* (*Babli Berakhoth*, *7a* and elsewhere) on the other hand, there seems to be no valid reason for doubting that he is the author of this small but sublime book. This *Midrash* is printed in the collection *Areze Lebanon* (Venice, 1601, 4to) under the title of "*Pireke Hekhaloth*" and "*Massekheth Hekhaloth*," and a MS of it is preserved in the University Library of Cambridge (Dd 10 11 7 2) The work, however, called "The Greater and the Lesser *Hekhaloth*," in thirty *Perakim*, printed in this century, somewhere in Poland, contains, besides the ancient literature, a good deal of matter which is of much later date

(5) *Seder Olam* (the Greater and the Lesser) are two historical *Midrashim*, the former of which belongs to the 2d century, whilst the latter (which is a mere extract of the former) belongs to a late age indeed (the Gaonaic) They have been repeatedly printed, always together, the *ed princ* being Mantua, 1513, 4to

(6) *Haggadah shel Pesah* is a liturgical *Midrash* of the middle of the 2d century, as far as its main portions go It exists now in three principal and several minor recensions in accordance with the various rituals (see MAḤZOR), and is recited at the domestic service of the first two Passover evenings The editions are too numerous to be mentioned, the *ed princ* being Constantinople, 1505, folio

(7) *Megillath Antiokhos* treats ostensibly, as its name indicates, of the sufferings of the Jews under Antiochus Epiphanes, and their deliverance from his tyranny, but in reality of their sufferings under Hadrian and their deliverance under Antoninus Pius The Aramaic text with the exception of a few interpolations, belongs to the middle of the 2d century This little "roll" was for the first time published by Filipowsky (London 1851, 32mo) A MS copy of the Hebrew is preserved in the University Library of Cambridge (Dd 8 34)

(8) *Zohar* (*Midrash Hazzohar*, *Midrasho shel Rabbi Shimeon b Yohai*, *Midrash Yehi Or*, &c) is a cabbalistic *Midrash* on the Pentateuch, Canticles, Ruth, and part of Lamentations It is variously ascribed to the famous R Shimeon (disciple of R Akibah, &c) and to R Mosheh b Shemtob of Leon (a second rate cabbalist of the time of Nahmanides and Ibn Addereth) The *Zohar* belongs, strictly speaking to neither of these, whilst, in a certain sense, it belongs to both The fact is—the nucleus of the book is of Mishnic times and R Shimeon b Yohai was the author of the *Zohar* in the same sense that R Yohanan was the author of the Palestinian Talmud, *i e*, he gave the first impulse to the composition of the book But R Mosheh of Leon,[6] on the other hand, was the first not only to copy and disseminate the *Zohar* in Europe, but also to disfigure it by sundry explanatory interpolations For more details see Lumby, "Introduction to the Epistle of Jude,' in the *Speaker's Commentary*, vol iv p 388 The first two editions of the *Zohar*[7] on the Pentateuch came out simultaneously (Mantua, 1558 60, 4to and Cremona, 1558, folio), and the *ed princ* on Canticles, Ruth and part of Lamentations came out at Salonika (1597, 4to) The best, though by no means critical, edition on the Pentateuch is that of Brody, 1873, 8vo Of translations, such as they are, there exist those of Knorr v Rosenroth, *Kabbala denudata* (vol i, Sulzbach, 1677, and vol ii., Frankfort, 1684, 4to), and Tholuck, *Wichtige Stellen*, &c (Berlin, 1824, 8vo), &c[8]

(9) *Pesikotho*[9] (commonly, but by mistake, called *Pesikta*) *derab Kohano* is a homiletic *Midrash* consisting of thirty two *Pesiktoth* for the principal festivals and fasts, and the historically noted sabbaths and other days It is of the end of the 3d or the beginning of the 4th century Having been but rarely quoted since the 12th century, so that most scholars knew of it only

---

[1] A valuable edition of this treatise (in Hebrew and English) has been published by Dr C Taylor, Cambridge, 1878

[2] To these we may add, for the sake of convenience although they do not, strictly speaking belong to the canonical *Mishnah* the *Perek Rabbi Meir* and the Agadic parts of the *Massekhtoth Ketannoth*

[3] Two collections of Talmudic *Agadoth* were made early in the 16th century —(1) *Haggadoth Hattalmud* Constantinople 1511 folio, of which apparently only five copies are in existence the finest of these being preserved in the University Library of Cambridge and (2) *En Yaakob* (or *En Yisrael*), of which numerous and cheap editions exist, the *ed princ* being that of Salonika, 1516 22

[4] Almost all that the latest critics have said concerning the age of the various *Targumim* and *Midrashim* will have to be unsaid Not only are negative statements difficult of proof in this case they are absolutely incorrect We shall only give two examples The statement ' *Vayyikra Rabbah* cannot be early, as Rashi did not know of it, since he nowhere mentions it, is doubly incorrect Rashi *does* quote it (*e g* on Haggai i 1) Again the statement "We must not omit to observe that no early Jewish commentator—Rashi, Ibn Ezra, &c —mentions the Targum either to Proverbs or to Job and Psalms, Nathan ben Jechiel (12th century) is the first who quotes it contains a *reductio ad absurdum* in itself For Nathan b Yehiel was as is well known, a somewhat older contemporary of Rashi (*ob* 1105), and lived full a hundred years before Ibn Ezra!

[5] See T B, *Synhedrin* 65b and 67 In the former place it distinctly speaks of the *Sepher Yezirah* (ספר יצירה) and, although in the latter place it speaks of the *Hilekhoth Yezirah* (הלכות יצירה), there cannot be a doubt that *Sepher* (ספר) and *Hilekhoth* (הלכות) are there identical Moreover, *Mishniyyoth* and *Halakhoth* are, in a certain sense convertible terms (see MISHNAH), and our book (as remarked above) consists of *Mishniyyoth*.

[6] R Mosheh of Leon is a fair sample of the mediocrity of his time in cabbalistic lore, and combined, as is usual, with his mediocrity an inimitable vanity, see MS Dd 11 22 (Cambridge University Library), leaf 2*a* "And I adjure every one who should deeply study this book, or who should copy it, or read it, that he do not blot out my name from my property (inheritance), for I have composed it This statement alone would suffice to prove that R Mosheh of Leon could never have ascribed a book composed by himself to anybody else

[7] The *Zohar*, cleared of the main works by which it is surrounded, and of the interpolations by which it has been disfigured both by its first European copyist and by others down even to our own days, was begun in Palestine late in the 2d or early in the 3d century, and finished, at the latest, in the 6th or 7th century It is impossible that it should have been composed after that time and before the Renaissance, as both language and contents clearly show

[8] Whilst the principal editions of the many textual extracts made from the *Zohar* (as the *Iddaroth*, &c) need not be specified here, those of the following supplementary and kindred works ought to be mentioned —(1) *Tikkune Hazzohar* (*ed princ* Mantua, 1557, 4to), and (2) *Zohar Hadash* (*ed princ* Cracow, 1603) Nor should the *Kontres missepher Hazzohar*, *Hibburo Tinyono* (by the otherwise very learned Yitshak b Mosheh of Satanow) be passed over It is a mere imitation of the *Zohar*,—an imposition of a kind which is a disgrace to literature

[9] For the three *Midrashim*—*Mekhilto*, *Siphro*, and *Siphere*—see under MISHNAH

indirectly, it was long considered lost, till, in 1868, Salomon Buber of Lemberg, a man of learning, wealth, and love for the ancient literature of his nation, edited it from four MSS, one of which (formerly in possession of Carmoly) is now preserved in the University Library of Cambridge (Add 1497) The printed edition appeared at Lyck, 8vo

(10) *Pesikto Rabbathi*, consisting in the latest edition of eighty-four *Piskoth*, is a *Midrash* of the same nature, and, in its main part, almost of the same date, as (9) Both drew from the same sources This *Midrash* has been edited five times,—the latest, best, and cheapest edition being that of Friedmann (Vienna, 1880, 8vo)

(11) *Tanna debe Eliyyahu* consists of two parts, the Greater (Rabbo) and the Lesser (Zutto),—the former in thirty one and the latter in twenty five *Perakim* It is an exegetical *Midrash*, the name of which is already known to the *Bereshith Rabbah* (c liv) and the Babylonian Talmud (*Kethuboth*, 106*a*) It is only uncritical criticism that can declare it a Gaonic work, although, like all other old books of the Jews, it is not without later additions *Ed princ*, Venice, 1598, 4to There are modern and cheap Polish editions

(12) *Midrash Rabbah* (רבה) or *Rabboth* (רבות) is chiefly an exegetical and homiletical *Midrash* on the Pentateuch and the "Five Rolls" (*Hamesh Megilloth*, *i e*, Canticles, Ruth, Lamentations, Ecclesiastes, and Esther) It is called *Rabbah* either from the third (the first distinctive) word of its beginning (רבי הושעי רבה) or from its being the most voluminous[1] *Midrash*, hence also *Rabbo* (רבא) The *Midrash* on Canticles (and Ecclesiastes) is now and then also called *Midrash Hazitha* (from the first distinctive word of the beginning חזית) These ten *Midrashim* are, certainly, of various styles and ages, yet none of them is, interpolation excepted, later than the beginning of the 5th century[2] It is remarkable that, although the *Megilloth* themselves had been early attached to the Pentateuch (since they were long before the 10th century, and still are, read through the synagogal year, even as was and still is the Pentateuch itself), the *Rabboth* had no common *editio princeps*[3]—that on the Pentateuch appearing for the first time in 1512 (Constantinople, folio), and that on the *Megilloth* in 1519 (somewhere in Italy, במדינת איטליאה, also in folio)[4] The latest and best edition is that of Vilna, 1880, folio A translation in German is now coming out at Leipsic, by Dr A. Wunsche

(13) *Pireke de Rabbi Eli'ezer* (also called *Boraitho de-Rabbi Eli'ezer*) is an astronomico-theosophical *Midrash* consisting of fifty four *Perakim* It goes through the so-called "eighteen benedictions," the signs of the zodiac, &c, but is unfinished It belongs, no doubt, to the 5th century The fact that the name "Fatima" occurs in it is no proof whatever that the book is post Mohammedan, as that name must have been already known to the idolatrous Arabs *Ed prin*, Constantinople, 1514, and with a Latin translation, Leyden, 1644, both editions being in 4to There are also now to be found cheap editions (Lemberg, Warsaw)

(14) *Tanhuma* is an exegetical and homiletical *Midrash* on the whole Pentateuch It is quoted according to the *Parshiyyoth* of the week Although originally of the end of the 5th or the beginning of the 6th century, it has now two principal additions, which form part of the book.—(1) several of the *Sheelloth* of Rab Ahai Gaon (of the 8th century), and (2) several pieces of the *Yesod* of R Mosheh Haddarshan, of Narbonne (of the 11th century) On its relation to the "*Yelammedenu*" (often quoted in the 11th century, but supposed to be lost) light will soon be thrown by the before mentioned Salomon Buber, who is now preparing a critical edition of it The *ed princ* of the *Tanhuma* is Constantinople, 1522, folio, and a very valuable MS copy of it is in the Cambridge University Library (Add 1212)

(15) *Bahir* is a small cabbalistic *Midrash* ascribed to the pre-Mishnic teacher, R Nehunyah b Hakkanah,—no doubt from its beginning with the words אמר רבי נחוניה בן הקנה. Nahmanides (*ob c* 1268) quotes this book often in his commentary on the Pentateuch, under the names of *Sepher Habbahir*, or of *Midrasho shel Rabbi Nehunyah b Hakkanah* Some have pronounced this work a late fabrication, but others, who have thoroughly studied it, justly describe it as "old in substance if not in form" *Ed princ*, Amsterdam, 1651, 4to A cheap edition appeared at Lemberg (1865, 8vo), and a MS of this work is preserved in the University Library of Cambridge (Dd 10 11 4)

(16) *Yalkut* is the only existing systematic if not exhaustive collection of the *Agadoth* on the whole Bible Its author drew not only from most of the *Midrashim* named in this article, but also from the *Boraithoth* (see MISHNAH), both *Talmudim*, and the Midrashic works now lost (as the *Abkhir*, *Hasshekhem*, or *Hashkem*, &c)[5] This fact constitutes one of the principal points of its value The author was R Shimeon, brother (and not son) of R Helbo, and father of the distinguished grammarian, critic, and divine R Yoseph Kara He lived somewhere in the north of France in the 11th century The *ed princ* of the *Yalkut* on Ezra, Nehemiah, and the books of Chronicles came out at Venice, 1517, folio (in the first Rabbinic Bible), that on the Prophets and Hagiographa in 1521, and that on the Pentateuch in 1526–27, both at Salonika, and in folio An English translation of the whole work has been undertaken by a band of Rabbinic scholars in Cambridge The first instalment, "The Yalkut on Zechariah," by E G King, B D, Hebrew lecturer of Sidney Sussex College, appeared in 1882 This specimen, besides giving a correct translation, contains many valuable notes

(17) *Lekah Tob* is a *Midrash* on the Pentateuch and the five *Megilloth*, by R Tobiyyahu b Eliezer of Greece, who lived during the crusade of 1096 This work draws, certainly, upon the old and well known *Midrashim*, and as such it would have thoroughly deserved the censure passed upon it by the witty but somewhat irreverent Abraham Ibn Ezra (in his preface to his commentary on the Pentateuch) But the *Lekah Tob* has also most valuable explanations both by the collector himself and by his father (R Eliezer), a fact passed over by Ibn Ezra in silence The *Lekah Tob* on Leviticus Numbers, and Deuteronomy came out for the first time at Venice, in 1546, folio, under the title of *Pesikto Zuttarto* (see leaf 93*b* in the postscript by the editor, הפסיקתא זוטרתא, which explains the somewhat vague title on the title-page פסיקתא זוטרתא או רבתא) In 1753–54 it was republished at Venice, with a Latin translation, by Blasius Ugolinus in his *Thesaurus Antiquitatum Sacrarum* (xv -xvi) under the name of *Pesictha* The *Lekah Tob* on Genesis and Exodus was

---

[1] The *Rabbah* on Genesis has 100 *Parshiyyoth*, that on Exodus 52, that on Leviticus 37, that on Numbers 23 and that on Deuteronomy 11 These five *Midrashim* are quoted according to their chapters The *Rabbah* on Canticles accommodates itself to the sacred text, and is quoted accordingly Ruth has 8 *Parshiyyoth*, and is quoted according to these Lamentations has 1 chapter consisting of 33 introductions (*Pethihotho Dehakhime*), accommodating itself, for the rest, to the sacred text Ecclesiastes has 3 *Sedarim*, and Esther has 6 *Parshiyyoth* At various times various modes of quoting these *Midrashim* are current,—the most common and most expedient however, being that of quoting them according to the verses of the Bible

[2] Here might with advantage be mentioned some pieces of literature which are kindred in nature, although some of them are of much earlier date, whilst others are much later, than the ten *Midrashim* just mentioned —(1) *Agadath Bereshith* on Genesis, in eighty three chapters —edited for the first time by R Menahem de Lonsano in his *Shete Yadoth*, Venice, 1618, 4to, (2) *Midrash Vayyisau* on Genesis xxxv 5, in one chapter,—to be found in Jellinek's *Bet ha Midrasch*, Leipsic, 1853 8vo, (3) amplifications of chapter lxv of our *Midrash Rabbah*, on Genesis xxviii 22, by the incorporation of the whole Apocryphon *Tobit* in Aramaic, &c (see *The Book of Tobit* &c, Oxford, 1878, 8vo), (4) *Midrash Vayyosha* on Exodus xiv 30, xv 1–18,—printed at Constantinople, 1519, 4to, a MS of this *Midrash* is preserved in the University Library, Cambridge (Add 854), (5) *Midrash Asereth Haddibberoth* on Exodus xx,—printed in Jellinek's *Bet ha Midrasch*, Leipsic, 1853, 8vo, (6) *Midrash Petirath Aharon* on Numbers xx 23–29, (7) *Midrash Petirath Mosheh* on Deuteronomy xxxiv, (8) *Midrash Abbo Gorion* on Esther, the last three are to be found in the before mentioned *Bet ha Midrasch*, (9) *Midrash Shemuel*, also called, from its beginning, *Eth laasoth Ladonai*, Constantinople, 1517, folio, (10) *Midrash Yonah*, Prague, 1595, 4to, (11) *Midrash Tillim* (*Tehillim*), 1512, (12) *Midrash Mishele*, 1517, the last two are printed at Constantinople, and in folio, (13) *Sepher Hayyashar* (in which a good many old traditions are preserved, although it is, of course, not the one mentioned in various books of the Bible), Venice, 1625, 4to, (14) *Dibere Hayyamim shel Mosheh*, Constantinople, 1516, 4to, a fragment of this is to be found in MS Add 532 4 in the University Library of Cambridge, (15) *Yosephon* (or *Josippon*), various works of Flavius Josephus worked up rather freely, Mantua, 1480, folio,—translated into Latin (German and Spanish) several times, (16) *Zerubbabel*, Constantinople, 1519, 8vo, (17) *Elleh Ezkerah* on the "Ten Martyrs" For several other smaller *Midrashim* see Jellinek's *Bet ha Midrasch*, i and ii, 1853, iii, 1855, iv, 1857, all at Leipsic, v, 1873, and vi, 1877, both at Vienna, and comp also Horowitz, *Sammlung Kleiner Midraschim*, i, ii, Frankfort, 1881–82 The *Midrashim* on Isaiah and on Job seem now irretrievably lost

[3] As if to compensate for this drawback, the well known Cornelio Adelkind brought out at Venice, in 1545, two editions of the *Rabboth* on the Pentateuch and *Megilloth*, the one at Bomberg's house and the other at Giustiniani's These two editions differ in nothing but in the title pages, &c, and the vignettes of the various books The former edition is in possession of Dr W Aldis Wright, and the latter in that of Dr C Taylor The fact of these editions having appeared simultaneously is, apparently, unknown to the bibliographers

[4] It is noteworthy that in this edition *Ahashverosh*, *i e*, Esther, stands between Lamentations and Ecclesiastes, with which latter the *Midrash* on the *Megilloth* ends

[5] We may mention here the *ed princ* of three cabbalistic Midrashic collections which go under the name of *Yalkut* —(1) *Yalkut Hadash*, Lublin, 1648, 4to, (2) *Yalkut Reubeni Hakkatan*, Prague, 1660, 4to, and (3) *Yalkut Reubeni Haggadol*. Wilhermsdorf, 1681, folio.

published, with a critical commentary, at Vilna, by Salomon Buber (1880, 8vo), where also simultaneously a third edition of this *Midrash* on the last three books of Moses, with a short commentary on it, came out by Aharon Mosheh Padova, of Carlin. The *Lekah Tob* on the five *Megilloth* is as yet unpublished; there exist, however, several good MSS. of it, both in public and private libraries, the finest copy in every respect being that preserved in the University Library, Cambridge (Add. 378. 1).

(18) *Menorath Hammaor* is a scientific, though incomplete, collection of the principal *Agadoth* of the *Talmudim* and *Midrashim*, by R. Yizhak Abohab the elder (flourished 13th century). The editions, with and without translations, are very numerous,—the *ed. princ.* being Constantinople, 1514, folio. There are translations in Spanish, Judæo German, and German, but not in English.

We append two specimens of *Midrashim*,—the first from *Pesikotho*, leaf 127*b*, and the second from *Midrash Shemoth Rabbah*, cap. ii.

First Specimen.—The Holy One (blessed be He) said to the Prophets,[1] Go ye and comfort ye Jerusalem!

Then went Hosea to comfort her and said The Holy One (blessed be He!) sent me to thee to comfort thee. She said What hast thou in thine hand to comfort me? The Prophet said (xiv. 6 [5]), I will be as the dew unto Israel! But Jerusalem said to him Only yesterday thou toldest me (ix. 16) Ephraim is smitten their root is dried up they shall bear no fruit yea though they bring forth yet will I slay even the beloved fruit of their womb! and now thou speakest to me thus. Which shall we believe the first or the second prophecy?

Then went Joel to comfort her and said The Holy One (blessed be He!) sent me to thee to comfort thee. She said to him What hast thou in thine hand to comfort me? The Prophet said (iv. 18) "And it shall come to pass in that day that the mountains shall drop down new wine and the hills shall flow with milk &c.! But Jerusalem said to him Only yesterday thou toldest me (i. 5) Awake ye drunkards and weep and howl all ye drinkers of wine, because of the new wine for it is cut off from your mouth and now thou speakest to me thus. Which shall we believe the first or the second prophecy?

Then went Amos to comfort her and said The Holy One (blessed be He) sent me to thee to comfort thee. She said to him What hast thou in thine hand to comfort me? The Prophet said (ix. 11) ' In that day will I raise up the tabernacle of David that is fallen! But Jerusalem said to him Only yesterday thou toldest me (v. 2) The Virgin of Israel is fallen she shall no more rise and now thou speakest to me thus. Which shall we believe the first or the second prophecy?

Then went Micah[2] to comfort her and said The Holy One (blessed be He!) sent me to thee to comfort thee. She said to him What hast thou in thine hand to comfort me? The Prophet said (vii. 18) Who is a God like unto Thee that pardoneth iniquity and passeth by the transgression of the remnant of His heritage? But Jerusalem said to him Only yesterday thou toldest me (i. 5) ' For the transgression of Jacob is all this and for the sins of the house of Israel, &c.! and now thou speakest to me thus. Which shall we believe the first or the second prophecy?

Then went Nahum to comfort her and said The Holy One (blessed be He) sent me to thee to comfort thee. She said to him What hast thou in thine hand to comfort me? The Prophet said (i. 1 [i. 15]) For the wicked shall no more pass through thee. But Jerusalem said to him Only yesterday thou toldest me (i. 11), There is one come out of thee that imagineth evil against the Lord a wicked counsellor! and now thou speakest to me thus. Which shall we believe the first or the second prophecy?

Then went Habakkuk to comfort her and said The Holy One (blessed be He) sent me to thee to comfort thee. She said to him What hast thou in thine hand to comfort me? The Prophet said (iii. 13) Thou wentest forth for the salvation of Thy people even for the salvation with Thine Anointed One! But Jerusalem said to him Only yesterday thou toldest me (i. 2) O Lord how long shall I cry and Thou wilt not hear even cry out unto Thee of violence and Thou wilt not save and now thou speakest to me thus. Which shall we believe the first or the second prophecy.

Then went Zephaniah to comfort her and said, The Holy One (blessed be He!) sent me to thee to comfort thee. She said to him What hast thou in thine hand to comfort me. The Prophet said (i. 12) And it shall come to pass at that time that I shall search Jerusalem with lights. But Jerusalem said to him Only yesterday [illegible] r the [illegible] prophecy

Then went Haggai to comfort her and said The Holy One (blessed be He) sent me to thee to comfort thee. She said to him What hast thou in thine hand to comfort me? The Prophet said (ii. 19) Is the seed yet in the barn yea as yet the vine and the fig tree and the pomegranate and the olive tree hath not brought forth from this day will I bless you. But Jerusalem said to him Only yesterday thou toldest me (i. 6) Ye have sown much and bring in little &c.! and now thou speakest to me thus. Which shall we believe the first or the second prophecy

Then went Zechariah to comfort her and said The Holy One (blessed be He) sent me to thee to comfort thee. She said to him What hast thou in thine hand to comfort me? The Prophet said (i. 15) And I am very sore displeased with the heathen that are at ease for I was but a little displeased and they helped forward the affliction. But Jerusalem said to him Only yesterday thou toldest me (i. 2) The Lord hath been sore displeased with your fathers and now thou speakest to me thus. Which shall we believe the first or the last prophecy

Then went Malachi to comfort her and said The Holy One (blessed be He!) sent me to thee to comfort thee. She said to him What hast thou in thine hand to comfort me. The Prophet said (iii. 12) And all nations shall call you blessed for ye shall be a delightsome land. But Jerusalem said to him Only yesterday thou toldest me (i. 10) I have no delight in you and now thou speakest to me thus. Which shall we believe the first or the last prophecy?

Then went all the Prophets to the Holy One (blessed be He!) saying to Him Lord of the Universe Jerusalem will not accept consolation at our hands. Then the Holy One (blessed be He) said to them I and you will together go to comfort her and this is why it says (Isaiah xl. 1) Comfort ye comfort ye my people, comfort her with me.[3] Comfort her ye celestial ones comfort her ye terrestrial ones! Comfort her ye living ones comfort her ye dead ones! Comfort her in this world comfort her in the world to come.

Second Specimen.—And whom does He try? The righteous one, for it says (Ps. xi. 5) "The Lord trieth the righteous." And by what does He try him? By the feeding of sheep. David He tried by sheep and found him a good shepherd, for it says (Ps. lxxviii. 70) ' And He took him from the 'restraints' of sheep.' What is the meaning of '*Mimmikhleoth*? The root is the same as that of '*vayyikkale* [*haggeshem*] (Gen. viii. 2), And the rain was restrained. David restrained the big sheep in favour of the small ones. He brought out first the young ones, so that they should feed on the tender herbs then he brought out the old ones that they should feed on the less tender herbs and, finally, he brought out the strong sheep that they should feed on the coarser herbs. Upon this the Holy One (blessed be He!) said, He who understandeth to feed sheep according to their strength let him come and feed My people! And this it is what is written (Ps. lxxviii. 71) From following the ewes great with young He brought him to feed Jacob His people!' And the same was the case as regards Moses, whom the Holy One (blessed be He) tried by sheep. Our rabbis say, When Moses our teacher (peace be upon him!) was feeding the sheep of Jethro in the wilderness, a kid ran away from him, and Moses ran after it till they came to a mountain hollow. When it had reached the mountain hollow there was a pool of water, and the kid stood still in order to drink. When Moses reached the kid he said to it, I did not know that thou didst run away from me because thou wast thirsty and faint. Thereupon he put it on his shoulders and walked back with it to the flock.[4] Then said the Holy One (blessed be He!), Thou art compassionate in the feeding of sheep belonging to mere flesh and blood (man) as thou livest, thou shalt feed My flock even Israel! Behold, this it is that is written (Exod. iii. 1), ' And Moses was feeding the flock, &c. (S. M. S. S.)

MIEDZYRZECZ PODLASKI (Russian, *Mejirryechie*), a district town of Russian Poland, in the government of Siedlce, 16 miles to the east of the government capital, on the railway between Warsaw and Brest-Litovskiy. It is first mentioned in the year 1390 as a feudal dominion of King Yaghello. After frequently changing hands it became the property of the Czartoryski, and afterwards of the Potocki family, whose palace is still to be seen in the town. Its 10,000 inhabitants—half of whom are Greek nonconformists, and half Jews and Poles—carry on some trade in bristles, and pursue minor industries.

MIERIS, the name of a family of artists who practised painting at Leyden for three generations in the 17th and 18th centuries.

I. Frans van Mieris, the elder, son of Jan van Mieris, a goldsmith and diamond setter, was born, according to Houbraken, at Leyden on the 16th of April 1635, and died there on the 12th of March 1681. His father wished to train him to his own business, but Frans preferred drawing to chasing, and took service with Abraham Torenvliet, a glazier who kept a school of design. As often happens, the youth's style was influenced by his earliest surroundings. In his father's shop he became familiar with the ways and dress of people of distinction. His eye was fascinated in turn by the sheen of jewellery and stained glass, and, though he soon gave up the teaching of Torenvliet for that of Gerard Dow and Abraham van den Tempel, he acquired a manner which had more of the finish of the exquisites of the Dutch school than of the breadth of the disciples of Rembrandt. It should be borne in mind that he seldom chose panels of which the size exceeded 12 to 15 inches, and whenever his name is attached to a picture above that size we may surely assign it to his son Willem or to some other imitator. Unlike Gerard Dow when he first left Rembrandt, or Jan Steen when he started on an independent career, he never ventured to design figures as large as life. Characteristic of his art in its minute proportions is a shiny brightness and metallic polish. The subjects which he treated best are those in which he illustrated the habits or actions of the wealthier classes, but he sometimes succeeded in homely incidents and in portrait, and not unfrequently he ventured on allegory. He repeatedly painted the satin skirt which Terburg brought into fashion, and he often rivalled Terburg in the faithful rendering of rich and highly coloured woven tissues. But he remained below Terburg and Metzu, because he had not their delicate perception of harmony or their charming mellowness of touch and tint, and he fell behind Gerard Dow, because he was hard and had not his feeling for effect by concentrated light and shade. In the form of his composition, which sometimes represents the framework of a window enlivened with greenery, and adorned with bas reliefs within which figures are seen to the waist, his model is certainly Gerard Dow. It has been said that he possessed some of the humour of Jan Steen, who was his friend, but the only approach to humour in any of his works is the quaint attitude and look of a tinker in a picture at Dresden, who glances knowingly at a worn copper kettle which a maid asks him to mend.

---

[1] Comp. *Pesikto Rabbathi* ed. Friedmann leaf 138*b*.

[2] See *Pesikto Rabbathi* (ed. Friedmann leaf 138*b*) where it says (before the paragraph on *Nahum*), Obadyah prophesied for Edom and Yonah for Nineveh. This, it is true, is a mere gloss, but it is the true reason why these two prophets are left out.

[3] There is a play here upon the meaning of the Hebrew עמי which may be read either *Ammi* ("my people") or *Immi* ("with me").

[4] Who, on reading this does not think of such passages in the New Testament as Matt. xviii. 12, xxv. 21, and John x. 14?

It is a question whether Houbraken has truly recorded this master's birthday. One of his best known pieces, a party of ladies and gentlemen at an oyster luncheon in the hermitage at St Petersburg, bears the date of 1650. Celebrated alike for composition and finish, it would prove that Mieris had reached his prime at the age of fifteen. Another beautiful example, the Doctor Feeling a Lady's Pulse in the gallery of Vienna, is dated 1656, and Waagen, in one of his critical essays, justly observes that it is a remarkable production for a youth of twenty-one. In 1657 Mieris was married at Leyden in the presence of Jan Potheuck, a painter, and this is the earliest written record of his existence on which we can implicitly rely. Of the numerous panels known to the writer of these lines, twenty-nine at least are dated,—the latest being an allegory, long in the Ruhl collection at Cologne, illustrating the kindred vices of drinking, smoking, and dicing, in the year 1680.

Mieris had numerous and distinguished patrons. He received valuable commissions from Archduke Leopold, the elector palatine, and Cosmo III, grand duke of Tuscany. His practice was large and lucrative, but never engendered in him either carelessness or neglect. If there be a difference between the painter's earlier and later work, it is that the former was clearer and more delicate in flesh, whilst the latter was often darker and more livid in the shadows. When he died his clients naturally went over to his son Willem, who in turn bequeathed his painting room to his son Frans. But neither Willem nor Frans the younger equalled Frans the elder.

II. WILLEM VAN MIERIS (1662–1747), son of Frans. His works are extremely numerous, being partly imitations of the paternal subjects, or mythological episodes, which Frans habitually avoided. In no case did he come near the excellence of his sire.

III. FRANS VAN MIERIS the younger (1689–1763) also lived on the traditions of his grandfather's painting room.

The pictures of all the generations of the Mieris family were successfully imitated by A. D. Snaphaan, who lived at Leyden, and [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] to the [illegible] [illegible] [illegible] [illegible]

MIGNARD, PIERRE (1610–1695), called—to distinguish him from his brother Nicholas—Le Romain, was the chief French portrait painter of the 17th century. He was born at Troyes in 1610, and came of a family of painters. In 1630 he left the studio of Simon Vouet for Italy, where he spent twenty-two years, and made a reputation which brought him a summons to Paris. Successful with his portrait of the king, and in favour with the court, Mignard pitted himself against Le Brun, declined to enter the Academy of which he was the head, and made himself the centre of opposition to its authority. The history of this struggle is most important, because it was identical, as long as it lasted, with that between the old guilds of France and the new body which Colbert, for political reasons, was determined to support. Shut out, in spite of the deserved success of his decorations of the cupola of Val de Grace (1664), from any great share in those public works the control of which was the attribute of the new Academy, Mignard was chiefly active in portraiture. Turenne, Bossuet, Maintenon (Louvre), La Valliere, Sevigne, Montespan, Descartes (Castle Howard), all the beauties and celebrities of his day, sat to him. His readiness and skill, his happy instinct for grace of arrangement, atoned for want of originality and real power. With the death of Le Brun (1690) the situation changed; Mignard deserted his allies, and succeeded to all the posts held by his opponent. These late honours he did not long enjoy; in 1695 he died whilst about to commence work on the cupola of the Invalides. His best compositions have been engraved by Audran, Edelinck, Masson, Poilly, and others.

MIGNONETTE, or MIGNONNETTE (*i.e.*, "little darling"), the name given to a popular garden flower, the *Reseda odorata* of botanists, a "fragrant weed," as Cowper calls it, highly esteemed for its delicate but delicious perfume. The mignonette is generally regarded as being of annual duration, and is a plant of diffuse decumbent twiggy habit, scarcely reaching a foot in height, clothed with bluntish lanceolate entire or three-lobed leaves, and bearing longish spikes—technically racemes—of rather insignificant flowers at the ends of the numerous branches and branchlets. The plant thus naturally assumes the form of a low dense mass of soft green foliage studded over freely with the racemes of flowers, the latter unobtrusive and likely to be overlooked until their diffused fragrance compels attention. The native country of the original or typical mignonette has sometimes been considered doubtful, but according to the best and latest authorities it has been gathered wild on the North African coast near Algiers, in Egypt, and in Syria. As to its introduction, a MS. note in the library of Sir Joseph Banks records that it was sent to England from Paris in 1742; and ten years later it appears to have been sent from Leyden to Philip Miller at Chelsea. Though originally a slender and rather straggling plant, there are now some improved garden varieties in which the growth is more compact and vigorous and the inflorescence bolder, though the odour is perhaps less penetrating. The small six-petalled flowers are somewhat curious in structure: the two upper petals are larger, concave, and furnished at the back with a tuft of club-shaped filaments, which gives them the appearance of being deeply incised, while the two lowest petals are much smaller and undivided; the most conspicuous part consists of the anthers, which are numerous and of a brownish red, giving the tone of colour to the inflorescence. In a new variety named Golden Queen the anthers have a decided tint of orange yellow, which imparts a brighter golden hue to the plants when in bloom. A handsome proliferous or double-flowered variety has also been obtained, which is likely to be a very useful decorative plant, though only to be propagated by cuttings; the double white flowers grow in large massive panicles (proliferous racemes), and are equally fragrant with those of the ordinary forms.

What is called tree mignonette in gardens is due to the skill of the cultivator. Though practically a biennial [illegible] hardy [illegible] since it flowers abundantly the first [illegible] and is utterly destroyed by the autumnal frost [illegible] [illegible] regarded as being annual [illegible] [illegible] by Decaisne [illegible] *[illegible]*, the mignonette, like many other plants treated in England as annuals, will continue to grow if kept in a suitable temperature. Moreover, the life of the plants of this semiannual habit may be prolonged into a second season if their flowering and seeding is persistently prevented. In applying these facts to the production of tree mignonette, the gardener grows on the young plant under glass, and prevents their flowering by nipping off the blooming tips of the shoots, so that they continue their vegetative growth into the second season. The young plants are at first supported in an erect position, the laterals being removed so as to secure clean upright stems, and then at the height of one or two feet or more, as may be desired, a head of branches is encouraged to develop itself. In this way very large plants can be produced.

For ordinary purposes, however, other plans are adopted. In the open borders of the flower garden mignonette is usually sown in spring, and in great part takes care of itself; but, being a favourite either for window or balcony culture, and on account of its fragrance a welcome inmate of town conservatories, it is also very extensively grown as a pot plant, and for market purposes with this object it is sown in pots in the autumn and thinned out to give the plants requisite space, since it does not transplant well, and it is thereafter specially grown in pits protected from frosts and marketed when just arriving at the blooming stage. In this way hundreds of thousands probably of pots of blooming mignonette are raised and disposed of year by year.

In classifying the odours given off by plants Rimmel ranks the mignonette in the class of which he makes the violet the type, and Piesse adopts the same view, referring it to his class of "iosmols" along with the violet and wallflower.

The name is sometimes, but it would appear less correctly, written mignonnette. The genus *Reseda* contains some other interesting and useful species,—among them the *Reseda Luteola*, which is commonly called dyer's weed and weld, and yields a valuable yellow dye.

MIGUEL, **Maria Evarist** (1802–1866), usually known as **Don Miguel**, whose name is chiefly associated with his pretensions to the throne of Portugal, was the third son of King John VI. of Portugal, and of Carlotta Joachima, one of the Spanish Bourbons; he was born at Lisbon on October 26, 1802. In 1807 he accompanied his parents in their flight to Brazil, where he was permitted to grow up a spoiled child and a worthless youth; in 1821, on his return to Europe, it is said that he had not yet learned to read. In 1822 his father swore fidelity to the new Portuguese constitution which had been proclaimed in his absence, and this led Carlotta Joachima, who was an absolutist of the extremest Bourbon type and otherwise hated her husband, to resolve to seek his dethronement in favour of Miguel, her favourite son. The insurrections which ensued (see PORTUGAL) resulted in her relegation to the castle of Queluz and the exile of Miguel (1824), who spent a short time in Paris and afterwards lived in Vienna, where he came under the teaching of Metternich. On the sudden death of John VI. in May 1826 Pedro of Brazil, his eldest son, renounced the crown in favour of his daughter Maria da Gloria, on the understanding that she should become the wife of Miguel. The last-named accordingly swore allegiance to Pedro, to Maria, and to the constitution which Pedro had introduced, and on this footing was appointed regent in July 1827. He arrived in Lisbon in February 1828, and, regardless of his promises, dissolved the new Cortes in March; having called together the old Cortes with the support of the reactionary party of which his mother was the ruling spirit, he got himself proclaimed sole legitimate king of Portugal in July. The power which he now enjoyed he wielded in the most tyrannical manner for the suppression of all liberalism, and his private life was characterized by the wildest excesses. The public opinion of Europe became more and more actively hostile to his reign, and after the occupation of Oporto by Don Pedro in 1832, the destruction of Miguel's fleet by Captain (afterwards Sir Charles) Napier off Cape St Vincent in 1833, and the victory of Saldanha at Santarem in 1834, Queen Christina of Spain recognized the legitimate sovereignty of Maria, and in this was followed by France and England. Don Miguel capitulated at Evora on May 29, 1834, renouncing all pretensions to the Portuguese throne, and formally promising never thenceforward to meddle in Peninsular affairs. He lived for some time at Rome, where he enjoyed papal recognition, but afterwards retired to Bronnbach, in Baden, where he died on November 14, 1866.

MIGULINSKAYA, a Cossack village (*stanitsa*) of Russia, in the government of the Don Cossacks, and in the district of Ust Medvyeditsa, 79 miles to the west of that town, on the left bank of the Don. It is one of the largest and wealthiest *stanitsas* of the government, and has 20,600 inhabitants, who are engaged in agriculture and stock-breeding, and in the export of agricultural produce.

MIKHAILOVSKAYA, a Cossack village (*stanitsa*) of Russia, in the government of the Don Cossacks, and in the district of Khopersk, 14 miles to the north-west of Uryupino, on the low left bank of the Khoper, which is inundated when the river is full. It has an important fair, where Tartars from Astrakhan exchange furs and cottons for manufactured and grocery wares imported from central Russia; the inhabitants of the district also sell corn, cattle, and plain woollen stuffs. Population, 18,000.

MILAN (the Latin *Mediolanum*, Italian *Milano*, and German *Mailand*), a city of Italy, situated near the middle of the Lombard plain, on the small river Olona, in 45° 27′ 35″ N. lat. and 9° 5′ 45″ E. long. It is 390 feet above the sea-level, and lies 25 miles south of the Alps at Como, 30 miles north of the Apennines, 20 miles east of the Ticino, and 15 miles west of the Adda.

The plain around Milan is extremely fertile, owing at once to the richness of the alluvial soil deposited by the Po, Ticino, Olona, and Adda, and to the excellent system of irrigation. Seen from the top of the cathedral, the plain presents the appearance of a vast garden divided into square plots by rows of mulberry or poplar trees. To the east this plain stretches in an unbroken level, as far as the eye can follow it, towards Venice and the Adriatic; on the southern side the line of the Apennines from Bologna to Genoa closes the view; to the west rise the Maritime, Cottian, and Graian Alps, with Monte Viso as their central point; while northward are the Pennine, Helvetic, and Rhetian Alps, of which Monte Rosa, the Saasgrat, and Monte Leone are the most conspicuous features. In the plain itself lie many small villages, and here and there a larger town like Monza or Saronno, or a great building as the Certosa of Pavia, makes a white point upon the greenery.

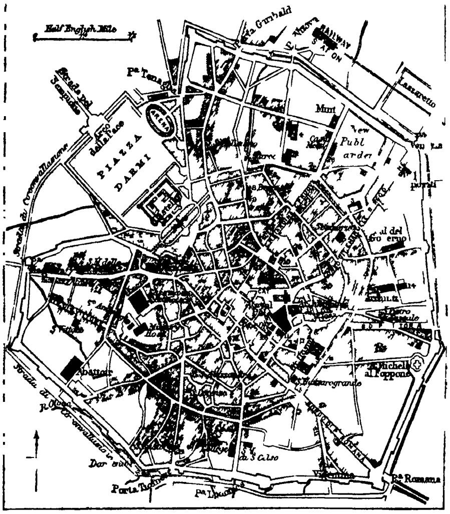
The commune of Milan consists since 1873 of the city within the walls (area 1513 acres) and the so-called Corpi Santi[1] without the walls (area 15,115 acres). The population of the whole area increased from 134,528 in 1800 to 242,457 in 1861, 261,985 in 1871, and 321,839 in 1881,—the city within the walls contributing 110,884 in 1801, 196,109 in 1861, 199,009 in 1871, and 214,004 in 1881. The climate is very variable; there is a difference of 41° Fahr. between the extreme summer heat and winter cold. The average number of wet days is 72, and of snowy days 10 per annum.

Milan is built in a circle, the cathedral being the central point. The city is surrounded by a wall 7 miles in circumference, and immediately outside the wall a fine broad thoroughfare makes the circuit of the city. The streets inside are for the most part narrow and crooked; the main streets are the Corso Vittorio Emmanuele, the Strada S. Margherita, the Via Manzoni, the Corso Porta Ticinese, and the Corso Porta Romana. There are few piazzas of any size; the largest is the Piazza del Duomo, which has recently been extended and the houses around it modernized. To the west of the city is the open space of the Foro Bonaparte and the Piazza d'Armi, with the square keep of the Visconti castle, flanked by two granite towers, between them. The castle was partly destroyed in 1447 by the Ambrosian republic, rebuilt by Francesco Sforza, enlarged by the Spanish governors, and taken by Napoleon in 1800, when the outer fortifications were razed to the ground, and the walls left as they now are. North of the Piazza d'Armi is the modern cemetery, with a special building and apparatus for cremation, erected in 1876.

Among the buildings of Milan the most important is the cathedral, begun under Gian Galeazzo Visconti, in 1386. It is built of brick cased in marble from the quarries which Visconti gave in perpetuity to the cathedral chapter. The name of the original architect is not known, but it is certain that many German master masons were called to Milan to assist the Italian builders. After St Peter's at Rome and the cathedral of Seville the Duomo of Milan is the largest church in Europe. It is 477 feet in length and 183 in width; the nave is 155 feet high, the cupola 226 feet and the tower 360 feet. The work was continued through many centuries and after the designs of many masters, notably of Amadeo, who carried out the octagon cupola, and of Tibaldi, who ornamented the doors and windows of the façade in the 16th century. The work was finished, under Napoleon, in 1805. The style is Gothic, though its purity is destroyed by the introduction of Romanesque windows and portals on the façade. The form of the church is that of a cross. Inside there are double aisles and aisles in the transept. The roof is supported by fifty-two columns with canopied niches for statues instead of capitals. The windows of the tribune contain brilliant painted glass. To the right of the entrance is the tomb of Archbishop Heribert, the champion of Milanese liberty; next to that is the tomb of Otho Visconti, founder of that family as a reigning house; and in the right transept the monument of Giacomo dei Medici, the corsair of Como, brother of Pope Pius IV. and uncle to Saint Carlo Borromeo. Under the dome in a crypt lies the embalmed body of this cardinal saint (1538–84), canonized for his good deeds during the great famine and plague of 1576. The body is contained in a silver sarcophagus faced with rock crystal. The roof of the cathedral is built of blocks of white marble, and the various levels are reached by staircases carried up the buttresses; it is ornamented with turrets, pinnacles, and two thousand statues.

---

[1] The name Corpi Santi (of doubtful origin) is also applied to the extra-mural portions of Cremona and Pavia.



Plan of Milan.

1 Piazza del Teatro
2 Piazza dei Mercanti
3 S. Angelo
4 Ospedale delle Fate bene Sorelle
5 Ospedale dei Fate bene Fratelli
6 Casa [illegible]
7 S. Maria del Carmine
8 Palazzo di Brera
9 [illegible]
10 [illegible]
11 Teatro [illegible]
12 [illegible]
13 [illegible]
14 Conservatorio di Musica
15 Teatro della Scala
16 [illegible]
17 Hotel [illegible]
18 Grand Hotel [illegible]
19 [illegible]
20 Hotel de la Ville
21 Hotel Gran Bretagna
22 Casa [illegible]
23 Galleria Vittorio Emanuele
24 S. L[illegible]
25 [illegible]
26 M[illegible]
27 Hotel de l'Europe

There are four other churches of interest in Milan. S. Ambrogio, the oldest, was founded by St Ambrose in the 4th century, on the ruins of a temple of Bacchus. It is remarkable for its fine atrium, and inside for the mosaics in the tribune, dating from the 9th century, and for the "pala" or plating of the high altar, a curious and ancient specimen of goldsmith's work. S. Maria delle Grazie is a Dominican church of the 15th century. The cupola, with exterior sides wrought in terra cotta, is attributed to Bramante. S. Gottardo is now built into the royal palace, and only the apse and the octagonal campanile remain. The latter, a beautiful example of early Lombard terra-cotta work, was built by Azzone Visconti in 1336, and was the scene of the murder of Giovanni Maria Visconti in 1412. The small church of San Satiro, founded in the 9th century, was rebuilt by Bramante in the 15th; the sacristy is one of that master's finest works.

The royal and archiepiscopal palaces are both worthy of note. The former stands on the site of Azzone Visconti's palace, and the present building was the vice-regal lodge of the Austrian governors. It contains one fine hall with a gallery supported by caryatides. The Broletto, or town hall, was built by Filippo Maria Visconti for his general Carmagnola, in 1415, who however never lived in it. The Great Hospital is a long building with a fine façade in terra cotta from the designs of the Florentine Antonio Averlino; it dates from the reign of Francesco Sforza (1456), and can accommodate 2400 patients. Among the modern buildings the most remarkable are the Arco della Pace, which stands at the commencement of the Simplon road (begun in 1804 by Napoleon, finished in 1833 under the Austrians), and the great Galleria Vittorio Emanuele, connecting the Piazza del Duomo with the Piazza della Scala, a graceful glass-roofed structure 320 yards long, 16 yards wide and 94 feet high, built in 1865–67 at a cost of 320,000 lire (£12,800). The Milanese are justly proud of this popular promenade as the finest of its kind in Europe, and in the best of their four considerable theatres—the Scala, built in 1778 on the site of a church raised by Beatrice Scala, wife of Bernabò Visconti—they also possess the largest theatre in Europe, with the single exception of the S. Carlo at Naples.

Milan is rich in works of art. It has been the home of many excellent sculptors and architects, among others of Amadeo and of Agostino Busti, known as Bambaia,—whose work may be seen in the cathedrals of Como and Milan, in the Certosa of Pavia, and in the terra-cotta buildings of the Lombard towns. Later on, towards the close of the 15th century, the refined court of Lodovico Sforza attracted such celebrated artists as Bramante the architect, Gaffurio Franchino the founder of one of the earliest musical academies, and Leonardo da Vinci, from whose school came Luini, Boltraffio, Gaudenzio Ferrari and Oggiono. In still more recent times Beccaria (1738–94) as a jurist, Monti (1754–1828) as poet, and Manzoni (1785–1873) as a novelist, have won for the Milanese a high reputation in the field of letters.

The picture gallery of the Brera is one of the finest in Italy. It possesses Raphael's famous "Sposalizio," and contains many frescoes by Luini, Gaudenzio Ferrari and Bramantino. The Venetian school is particularly well represented by works of Paolo Veronese, Paris Bordone, Gentile Bellini, Crivelli, Cima da Conegliano, Bonifazio, Moroni and Carpaccio. Luini may also be studied in the church of Monastero Maggiore, a large part of whose walls he painted in fresco. In the archaeological museum on the ground floor of the Brera are preserved many interesting monuments, among others the tomb of Beatrice della Scala and the equestrian monument of her husband Bernabò Visconti, as well as the most exquisite sepulchral monument of Gaston de Foix, the work of Agostino Busti. The library of the Brera contains upwards of 200,000 volumes, including some important Venetian chronicles, but it is not so rich in MSS. as the celebrated Ambrosian library, for which see LIBRARIES, vol. xiv. p. 531.

Agriculture.—The district of Milan is renowned for its excellent agriculture. It may be divided into two regions, where different systems of farming are pursued and different crops produced. The first region lies on the lower slopes of the Alps where they sink into the plain. This is called the dry Milanese, for it is watered by torrents only, which have worn themselves too deep a bed to allow of irrigation, and the peasants are obliged to collect the rain water in large mud-lined tanks called "poppe." The soil is for the most part thin and light, and is frequently washed down the incline into the plain; in some parts it is only kept in its place by stone walls reared at great cost. The farms are smaller here than in the lower plain, and are let on a system which is a compromise between the mezzadria, which [illegible] in the district, and regular leases. The tenant pays a money rent for the house, and for the land he either pays in kind [illegible] or [illegible] equivalent, supplemented by [illegible] given to the landlord. In cases where vines or fruit trees are grown, the landlord supplies and maintains them till they come into fruit. The landlord carries out all improvements, and the tenant holds the farm at his pleasure. The rotation of cropping is for three years. The value of these farms varies greatly, ranging from 7 to 14 lire the [illegible] 1000 square yards. The district produces [illegible] and wheat in [illegible] abundance, a little flax and millet, apples, and wine. The second agricultural district is that which lies in the plain; it is called the wet Milanese, from the elaborate system of irrigation which makes the [illegible] continuous succession of crops. The plain is traversed by innumerable canals at various levels, crossing one another on bridges or by siphons, so that the peasant can flood his fields at any moment. The system is as old as the 12th century; it was improved by Leonardo da Vinci, and is now the most perfect network of irrigation in Europe. The farms vary in extent from 1500 to 4500 pertiche. They are let upon leases for nine, twelve, or fifteen years, at rents ranging from [illegible] to 12[illegible] lire the pertica, while those near the city may bring from 1[illegible] to 20 lire. The rotation of cropping is five years. The meadows yield four crops of grass in the year: the first three—the maggengo, the agostino, and the terzuolo—are cut; the fourth is grazed off. Where the ground is perfectly flat and water can stagnate, rice is grown; this crop is continued for four years in succession; then the land is rested with cereals and grass. The other crops are maize and wheat. But the chief occupation is the supply of dairy produce. The cows are bought in the Swiss cantons of Uri, Zug, Lucerne, and Schwyz, the last furnishing the best milkers. The cheese called Parmesan comes from the Milanese, and [illegible] cheese, made of unskimmed milk, known as stracchino, is made principally at the village of Gorgonzola, [illegible] east of Milan.

Industries.—The industries of Milan [illegible] rapidly since the union of Italy, and [illegible] the first commercial centre in North Italy. The principal industry of Milan and the Milanese is the production and manufacture of silk. For feeding the worms mulberry [illegible] cultivated [illegible] plain, and the [illegible] silk thread is [illegible] 4000 cwt. of raw silk in the year [illegible] manufacture, but the Milanese [illegible] neighbours in the [illegible] Cotton is manufactured [illegible] linen at Cassano [illegible] of very excellent workmanship [illegible]

History.—Bellovesus, king of the Celts, [illegible] when Tarquinius Priscus was reigning in Rome, [illegible] founder of Milan. [illegible] the capital of [illegible] Gauls, and was taken by the Romans in 222 B.C. As [illegible] municipium it continued to increase in magnificence [illegible] and under Constantine it was the seat of the [illegible] of the West. Under [illegible] in the 4th century Milan, to judge from Ausonius's description (*Ordo Nobilium Urbium*) [illegible] have [illegible] buildings [illegible] at Milan [illegible] at the [illegible] of St Ambrose [illegible] his slaughter of the people [illegible] Ambrose is still venerated in Milan as the founder of the [illegible] and the compiler of the Ambrosian [illegible] which has [illegible] the diocese. After [illegible] death the period of invasion began, and Milan felt the power of the Huns under Attila (452), of the Heruli under Odoacer (476), and of the Goths under Theodoric (493). When Belisarius was sent by Justinian to recover Italy, Datius, the archbishop of Milan, [illegible] him, and the Goths were expelled from the city. But Uraia, nephew of Vitiges, the Gothic king, subsequently assaulted and retook the town after a brave resistance. Uraia destroyed the whole of Milan [illegible], and hence it is that this city, once so important a centre of Roman civilization, possesses so few remains of antiquity. Narses, in his campaigns against the Goths, had invited other barbarians, the Lombards, to his aid. They came in a body under Alboin, their king, in 568, and were soon masters of North Italy, and entered Milan the year following. Alboin established his capital at Pavia, and Milan remained the centre of Italian opposition to the foreign conquest.

The Lombards were Arians, and the archbishops of Milan from the days of Ambrose had been always orthodox. Though the struggle was unequal, their attitude of resolute opposition to the Lombards gained for them great weight among the people, who felt that their archbishop was a power around whom they might gather for the defence of their liberty and religion. All the innate hatred of the foreigner went to strengthen the hands of the archbishops, who slowly acquired, in addition to their spiritual authority, powers military, executive, and judicial. These powers they came to administer through their delegates, called viscounts. When the Lombard kingdom fell before the Franks under Charles the Great in 774, the archbishops of Milan were still further strengthened by the close alliance between Charles and the church, which gave a sort of confirmation to their temporal authority, and also by Charles's policy of breaking up the great Lombard fiefs and dukedoms, for which he substituted the smaller counties. Under the confused government of Charles's immediate successors the archbishop was the only real power in Milan. But there were two classes of difficulties in the situation, ecclesiastical and political, and their presence had a marked effect on the development of the people and the growth of the commune, which was the next stage in the history of Milan. On the one hand the archbishop was obliged to contend against heretics or against fanatical reformers who found a following among the people; and on the other, since the archbishop was the real power in the city, the emperor, the nobles, and the people each desired that he should be of their party; and to whichever party he did belong he was certain to find himself violently opposed by the other two. From these causes it sometimes happened that there were two archbishops, and therefore no central control, or no archbishop at all, or else an archbishop in exile. The chief result of these difficulties was that a spirit of independence and a capacity of judging and acting for themselves was developed in the people of Milan. The terror of the Hunnish invasion in 899, further assisted the people in their progress towards freedom, for it compelled them to take arms and to fortify their city, rendering Milan more than ever independent of the feudal lords who lived in their castles in the country. The tyranny of these nobles drove the peasantry [illegible] to seek the protection for life and property, the equality of taxation and of justice which could be found only inside the walled city and under the rule of the archbishop. Thus Milan grew populous and learned to govern itself. Its inhabitants [illegible] for the first time Milanese, attached to the standard of St Ambrose,—no longer subjects of a foreign conqueror, but a distinct people, with common public life and property of their own. For the further growth of the commune, the action of the great archbishop Heribert, the establishment of the carroccio, the development of Milanese supremacy in Lombardy, the destruction of Lodi, Como, Pavia, and other neighbouring cities, the exhibition of free spirit [illegible] Lombard league, and the battle of Legnano, see the articles ITALY [illegible] LOMBARDS.

After the battle of Legnano in 1174, although the Lombard cities failed to reap the fruit of their united action and fell to mutual [illegible], Milan continued to grow in material prosperity. After the peace of Constance (118[illegible]) the city walls were extended; the arts flourished, each having its own quarter under [illegible] who watched the interests of the trade. The manufacture [illegible] important industry. During the struggles with the emperor Barbarossa, when it seemed on the point of being destroyed, many Milanese saved themselves, their goods, and their families [illegible] should their city come safely out of her troubles. Hence arose the powerful fraternity of the Umiliati, who established their headquarters at the Brera, and began to develop the wool trade, and subsequently gave the first [illegible] to the production of silk. From this period also date the irrigation works which render the Lombard plain a fertile garden. The government of the city consisted of (1) a parlamento or consiglio grande, including all who possessed bread and wine of their own,—a council soon found to be unmanageable owing to its size, and reduced first to 2000, then to 1500, and finally to 800 members; (2) a credenza or committee of twelve members, elected in the grand council for the despatch of urgent or secret business; (3) the consuls, the executive, elected for one year, and compelled to report to the great council at the term of their office. The way in which the burghers used their liberty and powers, secured by the peace of Constance, in attacking the feudal nobility; how they compelled the nobles to come into the city and to abandon their castles for a certain portion of the year; how the war between the two classes was continued inside the city, resulting in the establishment of the podestà; and the nature and limits of this office,—all this has been explained in the article ITALY.

This bitter and well balanced rivalry between the nobles and the people, and the endless danger to which it exposed the city owing to the fact that the nobles were always ready to claim the protec-

soon germinate by pushing out a small tube which perforates the epidermis and thus gains access to the interior of the leaf, where it branches copiously, and forms a mass of thread like tissue called mycelium The germ-tubes of sporidia are unable to enter the leaves, &c, of grass plants In from six to ten days this mycelium gives rise to flask shaped bodies called spermogonia (vol ix p 831, fig 2 B *sp*), immediately under the surface of the leaf (usually the upper one), but breaking through it at the neck of the flask, out of which there protrudes a bunch of hairs Within the flasks are formed at the end of stalks many exceedingly small oval bodies called spermatia, which escape through the neck The function of these bodies has not yet been definitely made out, but that they bear a very striking resemblance to the male sexual organs of other fungi there can be no doubt In the same leaves and on the same mycelium there arise several days later numerous basin shaped bodies containing erect stalks, bearing at the apex a number of round æcidiospores (reproductive bodies) in vertical series (vol ix p 831, fig 2 B, *a*) These constitute the second generation On their escape they germinate by emitting a tube which, if the host on which they fall be a grass plant, enters the leaf through one of the stomata in the epidermis, and there by branching forms a new mycelium On this there soon appears, bursting through the epidermis, a new generation consisting of round or oval uredospores produced at the end of stalks (vol ix p 831, fig 2 C) The uredospores constantly reproduce this generation, and in such abundance that the grain crops are extensively ravaged by its attack It is in this generation that the term mildew is popularly given to the fungus Later in autumn on the same mycelium the two-celled teleutospores appear, and these after hibernating renew in spring the life-history This very remarkable cycle of generations was first traced by Professor de Bary

The *Hop Mildew* (*Sphærotheca Castagnei* Lev Order *Erysipheæ*) is a parasitic disease of the hop though it is often to be found on many other plants such as *Potentilla Spiræa Epilobium* balsams cucumbers dandelions plantains &c The thread like mycelium appears on the young shoots and leaves of the hop in white spots which gradually extend and finally unite This mycelium bears many minute round conceptacles (perithecia) which with their supporting threads are brown coloured Within each perithecium is found a somewhat oval body termed an ascus, containing eight ascospores (reproductive bodies)

The *Vine Mildew* (*Erysiphe Tuckeri* Berk Order *Erysipheæ*) is known only in one generation—called the oidium stage Soon after the flowering of the vine the attack takes place on the young leaves, from which the thin white mycelium spreads rapidly to the older leaves and twigs which it does not appear to affect so injuriously The chief damage is done to the grapes while they are in a very immature condition The mycelium which travels over the surface sends down at intervals into the tissues short irregular protuberances called haustoria, which perform for it the functions of roots Above these rise from the mycelium short stalks bearing each a single oval spore at the apex The disease spreads on the same plant not only by the extension of the mycelium but by the scattering and germination of the spores. Here no perithecia are known

The *Paper Mildew* (*Ascotricha chartarum* Berk Order *Erysipheæ*) grows on damp paper and therefore is saprophytic in its mode of life It consists at first of a branching filamentous mycelium on which minute globular spores occur Finally a round brown perithecium is formed among the threads which appear as radiating from it Within the perithecium are numerous linear asci containing each a row of dark elliptic ascospores

For the *Erysipheæ* generally see FUNGUS vol ix p 833

MILETUS, an ancient city on the southern shore of the Latmic Gulf opposite the mouth of the Mæander Before the Ionic migration it was inhabited by the Carians (*Iliad* ii. 876, Herod. i 146), other authorities call the original people Leleges, who are always hard to distinguish from Carians The Greek settlers from Pylus under Neleus massacred all the men in the city, and built for themselves a new city on the coast It occupied a very favourable situation at the mouth of the rich valley of [illegible] and was the natural outlet for the trade of southern Phrygia (Hipponax, *Fr.* 45); it had four harbours, one of considerable size Its power extended inland for some distance up the valley of the Mæander, and along the coast to the south, where it founded the city of Iasus The trade with the Black Sea, however, was the greatest source of wealth to the Ionian cities. Miletus like the rest turned its attention chiefly to the north, and after a time it succeeded in almost monopolizing the traffic. Along the Hellespont, the Propontis, and the Black Sea coasts it founded more than sixty cities—among them Abydus, Cyzicus, Sinope, Dioscurias, Panticapæum, and Olbia All these cities were founded before the middle of the 7th century, and before 500 B C Miletus was decidedly the greatest Greek city During the time when the enterprise and energy of the seafaring population, the ἀειναῦται, raised Miletus to such power and wealth, nothing is known of its internal history The analogy of all Greek cities, and some casual statements in later writers, suggest that the usual bloody struggles took place between the oligarchy and the democracy, and that tyrants sometimes raised themselves to supreme power in the city, but no details are known Miletus was equally distinguished at this early time as a seat of literature The Ionian epic and lyric poetry indeed had its home farther north, philosophy and history were more akin to the practical race of Miletus, and Thales, Anaximander, Anaximenes, Hecatæus, all belonged to this city The three Ionian cities of Caria—Miletus, Myus, and Priene—spoke a peculiar dialect of Ionic[1]

When the Mermnad kings raised Lydia to be a great military kingdom, Miletus was their strongest adversary War was carried on for many years till Alyattes concluded a peace with Thrasybulus, tyrant of Miletus, the Milesians afterwards seem to have peaceably acknowledged the rule of Crœsus On the Persian conquest Miletus passed under a new master it headed the revolt of 500 B C, and was taken by storm after the battle of Lade Darius treated it with peculiar severity, massacred most of the inhabitants, transported the rest to Ampe at the mouth of the Tigris, and gave up the city to the Carians Henceforth the history of Miletus has no special interest, it revived indeed when the Persians were expelled from the coast in 479 B C, and was a town of commercial importance throughout the Græco Roman period, when it shared in the general fortunes of the Ionian cities under the rule of Athenians, Persians, Macedonians, Pergamenians, and Romans in succession Its harbours, once protected by Lade and the other Tragusæan islands, were gradually silted up by the Mæander, and Lade is now a hill some miles from the coast Ephesus took its place as the great Ionian harbour in the Hellenistic and Roman times It was the seat of a Christian bishopric, but its decay was sure, and its site is now a marsh.

See Schroeder *Comment de Reb Miles* Soldan, *Rer Miles. Comment* Rayet, *Milet et le Golfe Latmique*, Head, "Early Electrum Coins, in *Numism Chron*, vol xvi

MILFORD, a seaport, market-town, and contributory parliamentary borough (one of the Pembroke district) of Pembrokeshire, South Wales, is finely situated on the north side of Milford Haven, about 8 miles west-north west of Pembroke The land locked estuary of Milford Haven stretches about 10 miles inland, with a breadth of from 1 to 2 miles In most places it has a depth of from 15 to 19 fathoms, and, as it is completely sheltered by hills, vessels can ride in it at anchor in all kinds of weather The royal dockyard, founded at Milford in 1790, was removed in 1811, and from that time trade has been in a languishing condition. The town possesses iron works The shipping trade is confined chiefly to coasting vessels, but with the completion of new docks, capable of receiving vessels of the largest tonnage, it is supposed that a considerable trade may be carried on with America The population of the urban sanitary district in 1871 was 3252, and in 1881 it was 3813

---

[1] The coinage of Miletus during this early period is an important subject on account of the wide commercial connexions of the city. The early electrum coinage belongs to the Phœnician or Græco-Asiatic standard, which was introduced from Phœnicia and spread over many of the Ionian and Thracian cities through the influence of Milesian trade Very archaic coins of Miletus Ephesus, Cyme, and Sardis are known of this standard, and at a somewhat later date of Chios, Samos, Clazomenæ, Lampsacus, Abydus, and Cyzicus. The lion is the regular Milesian type, often with a star beside or above him.

MILFORD, a post-village of the United States, in Worcester county, Massachusetts, lies 34 miles south west of Boston, at the junction of the Milford branch of the Boston and Albany Railroad with the Hopkinton, Milford, and Woonsocket Railroad It is one of the principal seats of the boot manufacture in New England, and also produces large quantities of straw goods The population was 9310 in 1880

MILICZ, or MILITSCH, of Kremsier, Moravia, was the most influential among those preachers and writers in Moravia and Bohemia who during the 14th century paved the way for the reforming activity of Huss and through him for that of Luther He was born about 1325, was already in holy orders in 1350, in 1360 was attached to the court of the emperor Charles IV, whom he accompanied into Germany in that year, and about the same time also held a canonry in the cathedral of Prague along with the dignity of archdeacon About 1363 he resigned all his appointments that he might become a preacher pure and simple, he addressed scholars in Latin, and (an innovation) the laity in their native Czech, or in German, which he acquired for the purpose The success of his labours in reclaiming the fallen made itself apparent in the reformation of a whole quarter of the city of Prague As he dwelt more and more on ecclesiastical abuses and the corruption of the clergy, and viewed them in the light of Scripture, the conviction grew in his mind that the "abomination of desolation" was now seen in the temple of God, and that antichrist had come, and in 1367 he went to Rome (where Urban V was expected from Avignon) to expound these views He affixed to the gate of St Peter's a placard announcing his sermon, but before he could deliver it was thrown into prison by the Inquisition Urban, however, on his arrival ordered his release, whereupon he returned to Prague, and from 1369 to 1372 preached daily in the Teyn Church there In the latter year the clergy of the diocese complained of him to the papal court at Avignon, whither he was summoned in Lent 1374, and where he died before his case was decided He was the author of a *Libellus de Antichristo*, written in prison at Rome, a series of *Postillæ* and *Lectiones Quadragesimales* in Latin, and a similar series of *Postils* in Czech

MILITARY FRONTIER (German, *Militargrenze*, Slavonic, *Granitza*), a narrow strip of Austrian Hungarian territory stretching along the borders of Turkey, which had for centuries a peculiar military organization, and from 1849 to 1873 constituted a crown-land As a separate division of the monarchy it owed its existence to the necessity of maintaining during the 15th, 16th, and 17th centuries a strong line of defence against the invasions of the Turks, and may be said to have had its origin with the establishment of the captaincy of Zengg by Matthias Corvinus and the introduction of Uskoks (fugitives from Turkey) into the Warasdin district by the emperor Ferdinand I By the close of the 17th century there were three frontier "generalates"—Carlstadt, Warasdin, and Petrinia (the last also called the Banal). After the defeat of the Turkish power by Prince Eugene it was proposed to abolish the military constitution of the frontier, but the change was successfully resisted by the inhabitants of the district, on the other hand, a new Slavonian frontier district was established in 1702, and Maria Theresa extended the organization to the march lands of Transylvania (the Szekler frontier in 1764, the Wallachian in 1766)[1]

As a reward for the service it rendered the Government in the suppression of the Hungarian insurrection in 1848, the Military Frontier was erected in 1849 into a crown-land, with a total area of 15,182 square miles, and a population of 1,220,503 In 1851 the Transylvanian portion (1177 square miles) was incorporated with the rest of Transylvania, and in 1871 effect was given to the imperial decree of 1869 by which the districts of the Warasdin regiments (St George and the Cross) and the towns of Zengg, Belovar, Ivanič, &c, were "provincialized" or incorporated with the Croatian Slavonian crown land In 1872 the Banat regiments followed suit, and in 1873 the old military organization was abolished in all the rest of the frontier Not till 1881, however, were the Croatian Slavonian march lands completely merged in the kingdoms to which they naturally belonged

The social aspect of the military frontier régime is interesting A communal system of land tenure natural to the old Slavonians was artificially kept in existence The mark or plot of ground assigned to the original family of settlers remained the property of the family as such, and could not be portioned out among the several members In this way the house community, all under the rule of the same house father and house mother (who were not necessarily man and wife nor the oldest members of the community), and all living within the same palisade sometimes came to number two or three hundred persons The 'family' dined in a common hall and after dinner discussed and settled matters affecting the common weal Every man possessing real property in the country, and capable of bearing arms, was liable to military service from his twentieth year The house communities are now beginning to avail themselves of the permissive partition laws, and strangers are free to come and acquire property in land. Watch towers with wooden clappers and the beacons which flashed the alarm along the whole frontier in a few hours are still features in the landscape

MILITARY LAW consists of the statutes, rules of procedure, royal warrants and orders and regulations which prescribe and enforce the public obligations of the officers, soldiers, and others made subject to its provisions Its essential purpose is the maintenance of discipline, but it also includes the administrative government of the military forces of the state, more especially in the matters of enlistment, service, and billeting The term "martial law" sometimes applied to it is as regards modern times at least, a misnomer For martial law as it is now understood applies not only to military persons but to the civil community, and may be described generally as the abrogation of ordinary law and the substitution for it of military force uncontrolled save by what, in the discretion of the commanding general, may be considered the necessity of the case

The military law of England in early times existed, like the forces to which it applied, in a period of war only.

---

[1] By 1848 the following had come to be the division of the Military Frontier —(1) *The Carlstadt (Carlowitz), Warasdin, and Banal Generalate* the Licca Regiment (headquarters at Gospich), the Ottochaz Regiment (Ottochaz), the Ogulin (Ogulin), the Sluin (Carlstadt), the Cross (Belovar), the St George's (Belovar), the 1st Banal (Glina), the 2d Banal (Petrinia) (2) *The Slavonian Generalate* the Gradiska Regiment (Neu Gradiska), the Brood Regiment (Vinkovcze), the Peterwardein (Mitrovicz), the Tchaikist Battalion (Titel) (3) *The Banat Generalate* the German Banat Regiment (Pancsova), the Wallachian Banat (Karansebes), the Illyrian Banat (Weisskirchen) (4) *The Transylvanian Generalate* The Szekler Regiment No 14 (Csik Szereda), the Szekler Regiment No 15 (Kezdi Vasarhely), the Wallachian No. 16 (Orlath), the Wallachian No 17 (Naszod) Twelve towns, known as "military communities," had communal constitutions not unlike those of the free towns of Hungary—Carlopago, Zengg, Petrinia, Kostainicza, Belovar, Ivanič, Brood, Peterwardein, Carlowitz, Semlin, Pancsova, and Weisskirchen.

Troops were raised for a particular service, and were disbanded upon the cessation of hostilities. The crown, of its mere prerogative, made laws known as Articles of War, for the government and discipline of the troops while thus embodied and serving Except for the punishment of desertion, which offence was made a felony by statute in the reign of Henry VI, these ordinances or Articles of War remained almost the sole authority for the enforcement of discipline until 1689, when the first Mutiny Act was passed and the military forces of the crown were brought under the direct control of parliament Even the Parliamentary forces in the time of Charles I and Cromwell were governed, not by an Act of the legislature, but by articles of war similar to those issued by the king and authorized by an ordinance of the Lords and Commons, exercising in that respect the sovereign prerogative This power of law making by prerogative was, however, held to be applicable during a state of actual war only, and attempts to exercise it in time of peace were ineffectual Subject to this limitation it existed for considerably more than a century after the passing of the first Mutiny Act From 1689 to 1803, although in peace time the Mutiny Act was occasionally suffered to expire, a statutory power was given to the crown to make Articles of War to operate in the colonies and elsewhere beyond the seas in the same manner as those made by prerogative operated in time of war In 1715, in consequence of the rebellion, this power was created in respect of the forces in the kingdom But these enactments were apart from and in no respect affected the principle acknowledged all this time that the crown of its mere prerogative could make laws for the government of the army in foreign countries in time of war The Mutiny Act of 1803 effected a great constitutional change in this respect the power of the crown to make any Articles of War became altogether statutory, and the prerogative merged in the Act of Parliament So matters remained till the year 1879, when the last Mutiny Act was passed and the last Articles of War were promulgated The Mutiny Act legislated for offences in respect of which death or penal servitude could be awarded, and the Articles of War, while repeating those provisions of the Act, constituted the direct authority for dealing with offences for which imprisonment was the maximum punishment as well as with many matters relating to trial and procedure The Act and the Articles were found not to harmonize in all respects Their general arrangement was faulty, and their language sometimes obscure In 1869 a royal commission recommended that both should be recast in a simple and intelligible shape In 1878 a committee of the House of Commons endorsed this view and made certain recommendations as to the way in which the task should be performed In 1879 the Government submitted to parliament and passed into law a measure consolidating in one Act both the Mutiny Act and the Articles of War, and amending their provisions in certain important respects This measure was called the "Army Discipline and Regulation Act, 1879" After one or two years' experience of its working it also was found capable of improvement, and was in its turn superseded by the Army Act, 1881, which now forms the foundation and the main portion of the military law of England It contains a proviso saving the right of the crown to make Articles of War, but in such a manner as to render the power in effect a nullity, for it enacts that no crime made punishable by the Act shall be otherwise punishable by such Articles As the punishment of every conceivable offence is provided for by the Act, any Articles made thereunder can be no more than an empty formality having no practical effect Thus the history of English military law up to 1879 may be divided into three periods, each having a distinct constitutional aspect —(1) that prior to 1689, when the army, being regarded as so many personal retainers of the sovereign rather than servants of the state, was mainly governed by the will of the sovereign, (2) that between 1689 and 1803, when the army, being recognized as a permanent force, was governed within the realm by statute and without it by the prerogative of the crown, and (3) that from 1803 to 1879, when it was governed either directly by statute or by the sovereign under an authority derived from and defined and limited by statute Although in 1879 the power of making Articles of War became in effect altogether inoperative, the sovereign was empowered to make rules of procedure, having the force of law, which regulate the administration of the Act in many matters formerly dealt with by the Articles of War These rules, however, must not be inconsistent with the provisions of the Army Act itself, and must be laid before parliament immediately after they are made Thus in 1879 the government and discipline of the army became for the first time completely subject either to the direct action or the close supervision of parliament

A further notable change took place at the same time The Mutiny Act had been brought into force on each occasion for one year only, in compliance with the constitutional theory that the maintenance of a standing army in time of peace, unless with the consent of parliament, is against law Each session therefore the text of the Act had to be passed through both Houses clause by clause and line by line The Army Act, on the other hand, is a fixed permanent code But constitutional traditions are fully respected by the insertion in it of a section providing that it shall come into force only by virtue of an annual Act of Parliament This annual Act recites the illegality of a standing army in time of peace unless with the consent of parliament, and the necessity nevertheless of maintaining a certain number of land forces (exclusive of those serving in India) and a body of royal marine forces on shore, and of keeping them in exact discipline, and it brings into force the Army Act for one year

Military law is thus chiefly to be found in the Army Act and the rules of procedure made thereunder, the Militia Act, 1882, the Reserve Forces Act, 1882, and the Volunteer Act, 1863, together with certain Acts relating to the yeomanry, and various royal warrants and regulations The Army Act itself is, however, the chief authority Although the complaint has been sometimes made, and not without a certain amount of reason, that it does not accomplish much that it might in point of brevity, simplicity, and clearness of expression, it is a very comprehensive piece of legislation, and shows some distinct improvements upon the old Mutiny Acts and Articles of War

The persons subject to military law are the officers on the active list and the soldiers of the regular forces (including the royal marines), the permanent staff of the auxiliary (i e, the militia, volunteer, and yeomanry) forces, and the officers of the militia. The above persons are amenable to its provisions at all times except while embarked on board a commissioned ship of the royal navy, when they become subject to the Naval Discipline Act and certain orders in council made under its authority Those who are subject to military law in certain circumstances only are—officers and men while serving in a force raised out of the United Kingdom and commanded by an officer of the regular forces, pensioners when employed in military service under the command of a regular officer, the non-commissioned officers and men of the militia, during training, when attached to the regulars or when permanently embodied, the officers of the yeomanry and the volunteers when in command of or attached to a body of men subject to military law, or when their corps is on actual military service, or when ordered on duty with their own consent, the men of the yeomanry when they or their corps are being trained, when they are attached to or acting with the regular forces, when their corps is on actual military service, or when serving in aid of the civil power, the men of the volunteers when they are being trained with or are attached to any body of troops, or when their corps is on actual military service, the men of the army reserve and the militia reserve when called out for training or on duty in aid of the civil power, any person who in an official capacity equivalent to that of an officer accompanies a body of troops on active service beyond the seas, any person accompanying a force on active service holding a pass from the general entitling him to be treated on the footing of an officer In this last category would of course be included newspaper correspondents, also sutlers and followers In one or two cases persons are subjected to military law to a limited extent and in respect only of certain offences Thus a militiaman even when not out for training or not embodied is liable to a military trial and punishment for fraudulent enlistment or making a false answer on attestation In the same manner an army reserve man may be tried and punished by court martial for neglect to appear at the place where he is bound periodically to report himself, or for insubordination to his superiors on these occasions, or for any fraud in connexion with the receipt of his pay A man of the army reserve or the militia reserve has the legal status of and in fact becomes a regular soldier when called out on occasions of national danger or emergency under the sovereign's proclamation

When a person subject to military law commits an offence he is taken into military custody, which means either arrest in his own quarters or confinement He must without unnecessary delay be brought before his commanding officer, who upon investigating the case may dismiss the charge if in his discretion he thinks it ought not to be proceeded with, or may take steps to bring the offender before a court martial Where the offender is not an officer he may dispose of the case summarily, the limit of his power in this respect being seven days' imprisonment with hard labour, fines not exceeding 10s for drunkenness, certain deductions from pay, confinement to barracks for twenty-eight days, this involving severe extra drills, deprivations, and other minor punishments Where the offence is absence without leave for a period exceeding seven days, the commanding officer may award a day's imprisonment in respect of each day of such absence up to twenty-one It is only in the case of the imprisonment exceeding seven days that the evidence before the commanding officer is taken on oath, and then only in the event of the accused so desiring it. The commanding officer is enjoined by regulation not to punish summarily the more serious kind of offences, but his legal jurisdiction in this respect is without limit as regards any soldier brought before him, and when he has dealt summarily with a case the accused is free from any other liability in respect of the offence thus disposed of In any instance where the commanding officer has summarily awarded imprisonment, fine, or deduction from pay, the accused may claim a district court martial instead of submitting to the award.

Ordinary courts martial are of three kinds, viz. —(1) a regimental court martial, usually convened and confirmed by the commanding officer of the regiment or detachment, presided over by an officer not under the rank of captain, composed of at least three officers of the regiment or detachment with not less than one year's service, and having a maximum power of punishment of forty-two days' imprisonment with hard labour, (2) a district court martial, usually convened by the general of the district, consisting in the United Kingdom, India, Malta, and Gibraltar of not less than five and elsewhere of not less than three officers, each with two years' service or more, and having a maximum power of punishment of two years' imprisonment with hard labour, (3) a general court martial, the only tribunal having authority to try a commissioned officer, and with a power of punishment extending to death or penal servitude, for offences for which these penalties are authorized by statute, it consists of not less than nine officers in the United Kingdom, India, Malta, and Gibraltar and of five elsewhere, each of whom must have over three years' service, five being not under the rank of captain. There is another kind of tribunal incidental to service in the field, or where, in the case of an offence against the person or property of an inhabitant, an ordinary court martial cannot be held, namely, a field general court martial This court may consist of three officers only, and it has the power of sentencing to death Another kind of court, called a summary court martial, may be held where an offence has been committed upon active service and an ordinary court cannot be conveniently assembled In the event of three officers not being available it may consist of two When thus constituted it can award only a "summary punishment" or imprisonment, where it consists of three officers, however, it can sentence to death In the case of a field general or a summary court martial many forms and precautions prescribed in the case of ordinary courts are not necessarily observed, the whole proceeding being from the necessity of the case a somewhat rough and ready means of dealing promptly with crime

The Army Act prescribes the maximum punishment which may be inflicted in respect of each offence That of death is incurred by various acts of treachery or cowardice before the enemy, or by when on active service interfering with or impeding authority, leaving without orders a guard or post, or when sentry sleeping or being drunk on a post, plundering or committing an offence against the person or property of an inhabitant, intentionally causing false alarms, or deserting Whether upon active service or not, a soldier also becomes liable to the punishment of death who mutinies or incites to or joins in or connives at a mutiny, who uses or offers violence to or defiantly disobeys the lawful command of his superior officer when in the execution of his office Penal servitude is the maximum punishment for various acts and irregularities upon active service not distinctly of a treacherous or wilfully injurious character, for using or offering violence or insubordinate language to a superior, or disobeying a lawful command when upon active service. The same punishment is applicable when not upon active service to a second offence of desertion or fraudulent enlistment (*i.e*, enlistment by one who already belongs to the service), certain embezzlements of public property, wilfully releasing without authority a prisoner or wilfully permitting a prisoner to escape, enlisting when previously discharged from the service with disgrace without disclosing the circumstances of such discharge, or any other offence which by the ordinary criminal law of England is punishable with penal servitude Imprisonment with hard labour for two years is the maximum punishment for minor forms and degrees of those offences which if committed upon active service would involve death or penal servitude, such as using or offering violence or insubordinate language to a superior or disobeying a lawful command, and for the following offences —resisting an escort, breaking out of barracks, neglect of orders, a first offence of desertion or attempted desertion or aiding or conniving at desertion, or of fraudulent enlistment, absence without leave, failure to appear at parade, going beyond prescribed bounds absence from school, malingering or producing disease or infirmity, maiming with intent to render a soldier unfit for service, an act of a fraudulent nature, disgraceful conduct of a cruel, indecent, or unnatural kind, drunkenness, releasing a prisoner without proper authority or allowing him to escape, being concerned in the unreasonable detention of a person awaiting trial, escaping or attempting to escape from lawful custody, conniving at exorbitant exactions, making away with, losing by neglect, or wilfully injuring military clothing or equipments, ill-treating a horse used in the service, making false or fraudulent representations in public documents, making a wilfully false accusation against an officer or soldier, making a false confession of desertion or fraudulent enlistment, or a false statement in respect of the prolongation of furlough, misconduct as a witness before a court martial or contempt of such court, giving false evidence on oath, any offence specified in relation to billeting or the impressment of carriages, making a false answer to a question put upon attestation, being concerned in unlawful enlistment, using traitorous or disloyal words regarding the sovereign, disclosing any circumstance relating to the numbers, position, movements, or other circumstances of any part of her majesty's forces so as to produce effects injurious to her majesty's service, fighting or being concerned in or conniving at a duel, attempting suicide, obstructing the civil authorities in the apprehension of any officer or soldier accused of an offence, any conduct, disorder, or neglect to the prejudice of good order and military discipline, any offence which if committed in England would be punishable by the law of England. There is another offence which can be committed by officers only, namely, "scandalous conduct unbecoming the character of an officer and a gentleman." It necessitates cashiering, a punishment which in the case of an officer may be awarded as an alternative to imprisonment in several other instances. There is also an offence peculiar to officers and non commissioned officers, that of striking or ill treating a soldier or unlawfully detaining his pay. A sentence of cashiering as distinguished from that of dismissal in the case of an officer involves an incapacity to serve the crown again. An officer may be also sentenced to forfeiture of seniority of rank and to reprimand or severe reprimand. A non commissioned officer may be sentenced to be reduced to a lower grade or to the ranks, and where sentenced to penal servitude or imprisonment is deemed to be reduced to the ranks. The commander in chief at home or the commander in chief in India or in either of the presidencies may also cause a non commissioned officer to be reduced to a lower grade or to the ranks. An acting non commissioned officer may be ordered by his commanding officer for an offence or for inefficiency or otherwise to revert to his permanent grade,—in other words, to forfeit his acting rank.

It will have been observed that persons subject to military law are liable to be tried by court martial for offences which if committed in England would be punishable by the ordinary law, and to suffer either the punishment prescribed by the ordinary criminal law or that authorized for soldiers who commit offences to the prejudice of good order and military discipline. The effect of the latter alternative is that for many minor offences for which a civilian is liable to a short term of imprisonment, or perhaps only to a fine, a soldier may be awarded two years' imprisonment with hard labour. A court martial, however, cannot take cognizance of the crimes of treason, murder, manslaughter, treason felony, or rape if committed in the United Kingdom. If one of these offences be committed in any place within her majesty's dominions other than the United Kingdom or Gibraltar, a court martial can deal with it only if it be committed on active service or in a place more than 100 miles from a civil court having jurisdiction to try the offence. With regard to all civil offences the military law, it is to be understood, is subordinate to the ordinary law, and a civilian aggrieved by a soldier in respect of a criminal offence against his property or person does not forfeit his right to prosecute the soldier as if he were a civilian.

The crimes for which soldiers are most usually tried are desertion, absence without leave, loss of necessaries, violence or insubordination to superiors, drunkenness, and various forms of conduct to the prejudice of discipline. The punishments are generally speaking gauged as much with regard to the character and antecedents of the prisoner as to the particular offence. For a first offence of an ordinary kind a district court martial would give as a rule fifty six days' imprisonment with hard labour, for a second or graver crime eighty four days. There are not many instances in which the period of imprisonment exceeds six months. Corporal punishment, which had been practically limited to offences committed upon active service, and in 1879 to crimes punishable with death, was finally abolished in 1881, and a summary punishment substituted. This summary punishment includes the liability for a term of three months to be kept in iron fetters and handcuffs, and while so kept to be attached to a fixed object so that the offender may remain in a fixed position for a period not exceeding two hours in the day for not more than three out of any four consecutive days and for not more than twenty one days in the aggregate. The offender may also be subjected to the like labour and restraint, and may be dealt with in the same manner as if sentenced to hard labour imprisonment. But these summary punishments are to be inflicted so as not to cause injury to health or leave a permanent mark on the offender. The first instances in which this kind of punishment was inflicted occurred during the campaign of 1882 in Egypt. Estimated by the results, the abolition of flogging does not appear to have injuriously affected discipline, the conduct of the troops in Egypt having been exceptionally good. The practice of marking a soldier with the letters "D" (deserter) or "BC" (bad character), in order to prevent his re enlistment, was abolished about a dozen years ago in deference to public opinion, which erroneously adopted the idea that the "marking" was effected by red hot irons or in some other manner involving torture. Military men for the most part regret its abolition, and maintain that if the practice were still in force the army would not be tainted by the presence of many bad characters who find means of eluding the vigilance of the authorities and enlisting after previous discharge.

The course of procedure in military trials is as follows. When a soldier is remanded by his commanding officer for trial by a district or general court martial, a copy of the charge, together with the statements of the witnesses for the prosecution (called the summary of evidence), is furnished to him, and he is given proper opportunity of preparing his defence, of communicating with his witnesses or legal adviser, and of procuring the attendance of his witnesses. Further, if he desires it, a list of the officers appointed to form the court shall be given him. Any officer is disqualified to sit as a member who has convened the court, who is the prosecutor or a witness for the prosecution, who has made the preliminary inquiry into the facts, who is the prisoner's commanding officer, or who has a personal interest in the case. The prisoner may also object to any officer on the ground of bias or prejudice similarly as a civilian might challenge a juror. Except as regards the delay caused by the writing out of the evidence, the procedure at a court martial is very much the same as that at an ordinary criminal trial,—the examination and cross examination of the witnesses, addresses of the prosecutor and prisoner, and the rules governing the admission or rejection of evidence being nearly identical. At a general court martial, and sometimes at a district court, a judge advocate representing the judge advocate general officiates, his functions being very much those of a legal assessor to the court. He advises upon all points of law, and sums up the evidence just as a judge charges a jury. When the prisoner pleads guilty the court finds a verdict accordingly, reads the summary of evidence, hears any statement in mitigation of punishment, and takes evidence as to character before proceeding to pass sentence. The sentence is that of the majority of the court, except where death is awarded, when two thirds of the members in the case of a general court martial and the whole in that of a field general court martial must concur. When an acquittal upon all the charges takes place the verdict is announced in open court, and the prisoner is released without any further proceeding. When the finding is "guilty," evidence as to character is taken, and the court deliberates in private upon the sentence, but the result is not made known until the proceedings are confirmed and promulgated. No conviction or sentence has any effect until it is thus confirmed by the proper authority. The confirming authority in the case of a regimental court is the commanding officer, in that of a district court martial the general officer commanding the district, and in that of a general court, if held in the United Kingdom her majesty, and if abroad in most cases the general officer commanding. The confirming authority may order the reassembling of the court in order that any question or irregularity may be revised and corrected, but not for the purpose of increasing a sentence. He may, however, of his own discretion, and without further reference to the court, refuse confirmation to the whole or any portion of the finding or sentence, and he may mitigate, commute, or entirely remit the punishment. In the case of a general court martial the proceedings are sent to the judge advocate general, who submits to the queen his opinion as to the legality of the trial and sentence. If they are legal in all respects he sends the proceedings to the commander in chief, upon whom rests the duty of advising the queen regarding the exercise of clemency. In addition to confirmation, however, every general or district court martial held out of India has another ordeal to go through. It is reviewed and examined in the office of the judge advocate general, and any illegality that may be disclosed is corrected and the prisoner is relieved of the consequences. To a certain extent a protection against illegality also exists in the case of regimental courts martial. A monthly return of those held in each regiment is laid before the general commanding the district or brigade, by whom any question that might appear to him doubtful would be referred to the adjutant general or the judge advocate general for decision. It is to be noted, however, that the judge advocate general, although fulfilling duties which are in their nature judicial, is only an adviser. He is not actually a judge in an executive sense, and has no authority directly to interfere with or correct an illegal conviction. In many cases the law thus provides no remedy for an officer or soldier who may have been wronged by the finding or sentence of a court martial,—for instance, through a verdict not justified by the evidence or through a non-observance of the rules and practice prescribed for these tribunals. A person who has suffered injustice may appeal to the Queen's Bench division of the high court of justice. But, speaking generally, that tribunal would not interfere with a court martial exercising its jurisdiction within the law as regards the prisoner, the crime, and the sentence. In most cases, therefore, the virtual protector of an accused person against illegality is the judge advocate general, who personally advises the queen and the military authorities that the law shall be complied with. As a privy councillor and member of the House of Commons that officer is responsible both to the queen and to parliament for the right and due administration of military law, and, notwithstanding his want of direct executive authority, it is not to be contemplated that any military officer would hesitate to act upon advice given by him with reference to a legal question connected with a court martial The department of the judge advocate general consists of the judge advocate general, who is a lawyer, a privy councillor, and a member of parliament, of a permanent deputy judge advocate general who is also a lawyer, and of three military officers as deputy judge advocates having special experience in the working of military law

The Army Act applies to European officers and soldiers serving in India in the same manner as to the rest of the army, but natives of India are governed by their own Articles of War, and in the case of civil offences they are dealt with according to the provisions of the Indian penal code The department of the judge advocate general in India is distinct from and independent of that of the judge advocate general of the army, and courts martial held in that country are not subject to the supervision of a professional lawyer Certain prominent irregularities led to the appointment of a barrister as judge advocate general in India in 1869, but after a few years that appointment again became filled by a military officer The staff of the department is, however, far more numerous in India than elsewhere There are judge advocates general for each of the presidencies, and a deputy judge advocate at each of the more important military centres

Statistics of Crime in the Army —Commissioned officers are rarely subjected to trial by court martial Where an officer commits himself in a military sense, and his misconduct is too serious to be passed over merely with a mark of official displeasure he is usually given and seldom fails to accept the alternative of resigning his commission In some instances the crown is advised to exercise its prerogative and remove him from the army on the ground that her majesty has no further occasion for his services In no circumstances can an officer or soldier claim a court martial as a right In the result, the annual number of trials of officers does not average more than four of late years Among the non commissioned officers and soldiers of the army, however, the trials and summary punishments by commanding officers are exceedingly numerous, as will presently be seen In India this observation hardly holds good for in that country desertion is physically almost impossible except at the two or three seaports where troops are stationed Absence without leave is for a similar reason of rare occurrence, while the fact of the troops living in their own cantonments and being free from many temptations of life existing in the large towns and garrisons at home, places them outside the influence of certain prevalent causes of crime For this reason mainly the proportion of courts martial held in 1881 was 107 per 1000 men at home as compared with 76 abroad Similarly the proportion of minor punishments per 1000 was 1449 at home to 1042 abroad It is also generally found that men engaged upon active service in the field commit less crime than those serving in ordinary circumstances But the general criminal statistics of the army for 1881 show a formidable amount of crime and punishment Upon an average strength of 181,186 non commissioned officers and men there were 16 523 courts martial, of which 179 were general, 8549 district, and 7795 regimental courts There were also 224,681 minor punishments by commanding officers, including 44,108 fines for drunkenness These figures generally show an increase of crime as compared with the two years immediately preceding, but these two exhibited a decrease upon previous years Of the offences tried by court martial in 1881 the following were the principal —mutiny 7, desertion 1597 offences in relation to enlistment (fraudulently enlisting while already belonging to the service or making false answers upon attestation) 1190, violence to and disobedience of superiors 1650, minor insubordination and neglect of orders 1472, quitting or sleeping on post 681, drunkenness on duty 2661, drunkenness (tried by court martial when the offence has been committed on a fifth occasion within twelve months) 2147, disgraceful conduct of various kinds 660, absence without leave not amounting to desertion 3293 making away with or losing by neglect equipment or necessaries 3768, and miscellaneous offences chiefly of an ordinary criminal character or to the prejudice of discipline 4181 Upon the 16,523 trials there were 349 findings of acquittal Regarding the punishments awarded, it appears that no soldier was sentenced to death during the year, and the other awards were as follows —penal servitude 104, imprisonment with or without hard labour (almost invariably the former) 12,125, discharge with ignominy without other punishment 42, stoppages of pay without other punishment 65, flogging (before the abolition of that punishment by the Act of

flogging)

were punished by reduction to a lower grade or to the ranks, while 591 more suffered imprisonment in addition to loss of grade, the former number being in the proportion of about 12 and the latter of 2 per cent. to strength Of the men tried 305 were pardoned

Military Law of other Countries —The administration of military law in other countries having large armies harmonizes in many important respects with that of England In some indeed it is a question whether their systems are not superior and in advance They have a considerable body of "auditors" or military lawyers who expound the law and do much to secure a uniform and exact administration of justice Thus in Austria there are about five hundred of these auditors, one being attached to each regiment In the same country there are also courts of appeal from the courts of first instance, these latter consisting of eight persons including the auditor Where the prisoner is a non commissioned officer or a private, that rank is represented on the court Here also the confirmation of superior authority is required In the German army there are general and regimental courts An auditor who is a lawyer is attached to each division, and it is his duty to expound the law, collect the evidence, and read it to the court in the presence of the prisoner, who is asked if he has any thing to say The court consists of eleven members of whom upon the trial of a private soldier or non commissioned officer three are of the rank of the accused The power of commanding officers in regard to disciplinary punishments is greater than in the British army, especially in relation to officers, who may be placed in arrest for fourteen days The non commissioned officers and privates are liable to extra guards, drills, fatigues, and different degrees of arrest, some of a very severe character Dismissal from the army, which is regarded as a most severe punishment, involving civil disgrace, is often awarded In Russia there are three kinds of military courts—namely the regimental court martial, the tribunals of military districts, and the supreme tribunal at St Petersburg They are permanent courts, are attended by legal persons, and in certain instances have jurisdiction over the civil population as well as the army There is a judge advocate general at St Petersburg, where the supreme tribunal consists of general officers and high war office functionaries who have studied military law or possess a large experience of its working In Italy there are permanent military tribunals for the trial of non commissioned officers and soldiers, while special tribunals are appointed to try officers The court is the absolute judge of the facts, but regarding legal errors or irregularities an appeal lies to the supreme war tribunal, which consists of four civilian judges and three general officers The French code corresponds in many respects with those of the other great Continental armies, but it tends rather to give individual officers large powers of imprisonment graduated according to their rank The chief distinctive feature of the French system is the institution of regiments of discipline for refractory characters When the general officer s power of imprisonment (two months) is exhausted the offender may be sent before a court of discipline and by them drafted into a *compagnie de discipline* and cases of habitual misconduct are thus dealt with, the man being struck off the strength of his original corps and transferred to one in Algeria The military law of the United States is founded upon and proceeds much upon the same lines as that of England (J C OD)

MILITARY TACTICS See WAR

MILITIA The militia of the United Kingdom consists of a number of officers and men maintained for the purpose of augmenting the military strength of the country in case of imminent national danger or great emergency In such a contingency the whole or any part of the militia is liable, by proclamation of the sovereign, to be embodied,—that is to say, placed on active military service within the confines of the United Kingdom The occasion for issuing the proclamation must be first communicated by message to parliament if it be then in session, if it be not sitting, parliament must be called together within ten days For the purpose of keeping the force in a condition of military efficiency, the officers and men are subjected to one preliminary training for a period not exceeding six (usually about two) months, and further to an annual training not exceeding fifty six (usually twenty eight) days The force is composed of corps of artillery, engineers, and infantry Infantry militiamen are formed into battalions constituting part of the territorial regiment of the locality of which the regular forces are the senior battalions The officers and men when called out are liable to duty with the regulars and in all respects as regular soldiers within the United Kingdom Of late years the men have been raised exclusively by voluntary enlistment, but where a sufficient number for any county or place is not thus raised a ballot may be resorted to in order to complete the quota fixed by the queen in council for that county or place Each man is enlisted as a militiaman for the county, to serve in the territorial regiment or corps of the district The period of engagement is not to exceed six years, but during the last of these years a militiaman may be re-engaged for a further period also not exceeding six years.

Men who illegally absent themselves are liable, in addition to punishment for the offence, to make up for the time of their absence by a corresponding extension of their service The officers are appointed and promoted by the crown, but first appointments are given to persons recommended by the lord lieutenant of the county who may be approved as fulfilling the prescribed conditions in respect of age, physical fitness, and educational qualifications Since 1877 the officers have been permanently subject to military law The general body of the non commissioned officers and men are so subject only when called out for training or embodiment At other periods they have simply the legal status of civilians, except as regards a liability to trial and punishment for offences in connexion with enlistment or for military offences committed while called out Each militia regiment has a permanent staff, consisting of an adjutant and a small body of non-commissioned officers and drummers, to conduct the recruiting drills and ordinary business of the corps, and the members of this permanent staff are always subject to military law They mostly consist of non commissioned officers who belong to or have served in the regular portion of the territorial regiment Many of the militia corps have their headquarters at the brigade depôt or local establishment of the territorial regiment and all are under the general supervision of the (regular) colonel commanding the brigade depôt The area of service does not extend beyond the United Kingdom, but those who voluntarily offer to serve in the Channel Islands, the Isle of Man, Malta, or Gibraltar may be employed therein The uniform of the officers and men of the militia is precisely the same as that of the regular corps with which they are associated, or rather of which they form part, except that in addition to the regimental distinguishing mark they bear the letter "M upon their appointments, to denote that they belong to the militia portion of the corps

As above stated the ranks of the militia are usually filled by voluntary enlistment, but by a statute which, though temporarily suspended, can be put in force provisions are made for filling up any deficiency in the allotted quota in any county, city, or riding by ballot of the male inhabitants if within certain limits of age The enactment provides as follows —

> The secretary of state is to declare the number of militiamen required whereupon the lord lieutenant is to cause meetings to be held of the lieutenancy for each subdivision To these meetings the householders of each parish are to send in lists of all male persons between the ages of eighteen and thirty dwelling in their respective houses Before the ballot however the parish may supply volunteers to fill up the quota every volunteer so provided and approved counting as if he were a balloted person If a deficiency still exists the persons on the lists shall be balloted for and double the number of those required to supply the deficiency shall be drawn out. Any person whose name is so drawn may claim exemption or object and the deputy lieutenants settle the question of his liability to serve From the corrected list those who are of the requisite physique (the height is 5 feet 2) are enrolled in the order in which their names are numbered until the quota is completed If the list is not sufficient to fill the quota another ballot in the same manner is to be taken Any balloted man becoming liable to serve may, however provide a substitute who has the requisite physical qualifications and is not himself liable to serve

Within the general body of the militia is contained another having an additional and important obligation in the matter of service It is called the "militia reserve,' and is formed of men who voluntarily undertake a liability to join the regular forces and serve in any place to which they may be ordered in case of the proclamation of a state of imminent national danger or great emergency In this respect they are in fact upon the same footing as the army reserve, and on the occasion of the mobilization of 1878 more than 20,000 of these men became part of the regular army The present strength of the militia reserve is a little under 29,000 men, and judging by past experience it may be computed that about 25,000 could be at once added to the ranks of an army in the field in the event of national danger or emergency It is to be observed, however, that every man thus added to the regulars would be taken away from the effective strength of the militia

There is no statutory provision for the number of men to be maintained, that number being what from time to time may be voted by parliament The latest information available respecting the actual condition of the militia of Great Britain relates to the year 1881, and that of Ireland to 1880, the militia of the latter country for obvious political reasons not having been called out for training in 1881 or 1882 Taking the militia of the United Kingdom in 1881, we find that the establishment provided for was 139,501, of whom 18,618 were artillery, 1317 engineers, and 119,566 infantry Divided into ranks, this establishment was made up of 3534 sergeants and 1260 drummers of the permanent staff and of the general body 3909 officers, 2520 sergeants, 5040 corporals, and 123,238 privates The number actually enrolled was 127,868 of all ranks, leaving 11,633 wanting to complete Of the number enrolled 84,864 belonged to English, 14,138 to Scotch, and 28,866 to Irish regiments, the numbers wanting to complete being for England 7420, for Scotland 162, and for Ireland 4051 As the Irish regiments were not called out, our information regarding the actual effective condition of the force as shown at the annual training does not include Ireland With regard to the English regiments, 74,945 were present out of an enrolled strength of 84,864 Of the absentees 3144 were with and 6775 without leave In the Scotch regiments, 12,401 appeared at the training, and of the absentees 616 were with leave and 1121 without Of the total establishment (106,584) for Great Britain, 99 002 were enrolled, and of those enrolled 87,346 presented themselves and 3760 were absent with leave and 7896 actual defaulters Of the English regiments five sixths and of the Scotch regiments two thirds were born in the county to which their regiments respectively belonged Of 92,677 men (for Great Britain) whose occupations are disclosed, 17,665 were artisans, 22,221 mechanical labourers, 26,227 agricultural labourers, and 26,564 other trades Speaking approximately, more than one half of the men were between twenty and thirty years of age, about 4 per cent between seventeen and eighteen, about 9 per cent between eighteen and nineteen, and about 12 per cent between nineteen and twenty, while some 20 per cent were over thirty years of age More than one half those inspected in 1881 were between 5 feet 5 inches and 5 feet 7 inches in height, about 20 per cent were under 5 feet 5 inches, while only 585 out of a total of 92,677 were 6 feet and upwards At the date of inspection there were 296 men in military confinement and 465 in the custody of the civil power On the last occasion (1880) on which the Irish militia were called out, upon an establishment of 32,813 and an enrolled strength of 30,515 the number present at the training was 26,399, leaving 706 absent with and 2264 without leave Regiments numbering in the aggregate 1146 men were not trained

As distinguished from the regular forces or standing army, the militia has been described as the constitutional military force of the country, and its history justifies the description, at least up to a recent period when it lost its distinctive character and became to a great extent merged in the regular army It is the oldest force Britain possesses, and in fact represents the train bands of early English history Its origin is to be found in the obligation of all freemen between certain ages to arm themselves for the preservation of the peace within their respective counties, and generally for the protection of the kingdom from invasion This obligation, imposed in the first instance upon the individuals themselves, became shifted to the owners of land, who were compelled to keep up their proportion of horses and armour for the national defence. The forces were placed under the lieutenant of the county, empowered in this respect by a commission from the crown This prerogative of the sovereign, which had been in some instances a matter of controversy, was declared by statute shortly after the Restoration By the same statute the militia of each county was placed under the lieutenant, who was vested with the appointment of officers, but with a reservation to the crown in the way of commissioning and dismissal The cost of the annual training—for fourteen days—fell upon the local authority Offences against discipline were dealt with by the civil magistrates, but with a power to the officers of fining and of imprisoning in default. Upon this footing the militia of England remained for nearly a century, with the general approval of the community It was recognized as an instrument for defence and for the preservation of internal order, while it was especially popular from the circumstance that from its constitution and organization the crown could not use it as a means of violating the constitution or abridging the liberty of the subject It was controlled and regulated in the county, it was officered by the landowners and their relatives, its ranks were filled by men not depending for their subsistence or advancement upon the favour of the crown, its numbers and maintenance were beyond the royal control its government was by statute While the supreme command was distinctly vested in the crown, every practical security was thus taken against its use by the crown for any object not constitutional or legitimate It was regarded as, and was, in fact, the army of the state as distinguished from the standing army, which was very much the army of the king personally The latter consisted of hired soldiers, and was more than once recruited by a conscription, confined, however, to persons of the vagrant class not having a lawful employment, while the former was mainly composed of those having a fixed abode and status The militia thus enjoyed for many years as compared with the regular forces a social as well as a constitutional superiority About the middle of the last century the militia was reconstituted, with certain modifications not involving a sacrifice of the principle of its local government but strengthening somewhat the supervising influence of the crown Thus the king directly appointed the permanent staff and was given a veto upon the appointment and promotion of the officers who were to have a property qualification A quota was fixed for each county, to be raised by ballot of those between the ages of eighteen and forty five, each parish having the option of supplying volunteers at its own cost, and each man balloted being permitted in lieu of serving to pay £10 to provide a substitute When called out for service the pay was to be the same as that of the regulars and while embodied or assembled for annual training the officers and men were placed under the Mutiny Act and Articles of War, with, however, a proviso that in time of training no punishment was to extend to ' life or limb The crown was given the power to call out the militia in case of apprehended invasion or of rebellion, and associate it with the regular army, but only upon the condition of previously informing parliament if then sitting, and if it were not sitting of calling parliament together for the purpose A further and important security was established to prevent an unconstitutional use of the militia by the crown the estimate for its training was framed each year, not by an executive minister of the sovereign, but by the House of Commons itself Upon the initiative of a committee of the House, an Act was passed providing for the pay and clothing of the militia for the year Upon this footing substantially the militia of England remained for many years, the Irish and Scotch militias being meantime brought under the same conditions by various enactments The force was embodied on several occasions during the last and in the early years of the present century, and it contributed largely to the army engaged in the Peninsula From 1803 to 1813 just 100,000 men, or two-fifths of those raised for the army, came from the militia In this way however, it lost its distinctive character as a defensive force During the peace which followed the final fall of Napoleon the militia was suffered to fall into decay, and up to 1852 it had only a nominal existence in the shape of an effete permanent staff with no duties to perform In 1853 the militia was revived just in time to enable it to fulfil most valuable functions In the war with Russia it was embodied and did garrison duty not only in the United Kingdom but in the Mediterranean garrisons, thus enabling the authorities to send most of the available regular troops to the scene of hostilities It further contributed many officers and some 30,000 men to the line It still gives annually about 8000 recruits to the regulars During the Indian mutiny it filled scarcely less useful functions when again called out It has since then been regularly assembled for annual training, and when it is brigaded with the regular forces at Aldershot and other camps of instruction its military aptitude and proficiency have generally elicited the surprised admiration of professional soldiers In 1871 an important constitutional change was made It was part of the new army system inaugurated in that year that the control of the militia should be removed from the lord lieutenant of the county and vested wholly in the crown It has now virtually ceased to exist as a distinct body, and is a part of the regular forces with a limitation as to the time and area and other conditions of service. There is no longer a regiment of militia The body that would formerly be thus described is now a collection of militiamen of a regiment largely composed of regulars. The votes for the maintenance of the militia are now part of the army estimates The officers of the militia and the line are eligible for duty with either force, and may sit upon courts martial indiscriminately This practical amalgamation of the old constitutional force with the standing army may appear theoretically open to the objection that it is thereby placed under the direct control of the sovereign But the day has passed when such an objection could have any value The fact of the whole army being placed in all respects under the direct control of a minister responsible not only to the crown but to parliament is enough to dissipate any constitutional apprehensions under this head

The only colonial militia that forms an effective force is that of Canada, which is organized as an efficient local army The Government of the Dominion includes a minister of militia and defence The force is placed under the command of a general icer, assisted by an adjutant general, belonging to the regular [illegible] ral *of the governing* body a [illegible] of the Royal Artillery and Royal Engineers, as well as schools of gunnery and musketry For military purposes the Dominion is mapped out in twelve districts The militia is divided into the active and the reserve, and the male inhabitants between the ages of eighteen and sixty, with the usual exceptions, are liable to military service the extent of which varies with the age of each man, the larger amount of duty falling upon the younger The active militia comprises 12 regiments of cavalry, 17 field and 31 garrison batteries of artillery besides a mountain battery, 4 companies of engineers, 2 mounted rifle corps, 97 battalions of from 5 to 10 companies each and 16 independent companies of infantry The uniform is for the most part like that of the regular army, and the organization and general efficiency of the whole body have been very favourably reported upon Although the obligations of the Canadian militia are purely local, a large number on a late occasion offered themselves for general service, and, in the event of a war on a large scale, it is believed that the force would contribute a valuable addition to the fighting strength of the imperial army (J C OD)

MILK is the fluid secreted by the mammary glands of the division of vertebrate animals called *Mammalia* These glands are in a rudimentary form in the Monotremes In *Ornithorhynchus* there is no nipple, but the mouth and tongue are closely applied over the area on which the ducts open, and the fluid is withdrawn by suction on the part of the young and compression of the gland by the mother In *Echidna* the ducts of the gland open into a small pouch, foreshadowing the larger pouches of marsupials In Marsupials the glands are more compact, and have a greater number of lobules They are found behind the marsupial depressions or those of the pouch, they are not fewer than two on each side nor more than thirteen, six on each side and one midway The ducts, long and slender during lactation, open on a nipple which is covered by a reflexion of the skin at the back of the pouch, thus forming a kind of hood or sheath The nipple is protruded beyond the hood during lactation, and is much elongated The number of these nipples bears a relation to the number of young at a birth, thus the kangaroo, with one at a birth, has four nipples (two, generally the anterior pair, being in use), whilst the Virginian opossum, which produces six or more at a birth, has thirteen nipples Rodents show a corresponding provision for the nourishment of the young in the number of nipples A seeming exception is the common guinea pig, which frequently has eight, ten, or twelve young at intervals of two or three months, and yet the mother has only two teats to serve them, turn and turn about, the original stock of the domestic species breeds, however, only once annually, and has but one to two young, so the domestic variety is a curious anomaly due to the artificial circumstances of its life. In the porcupines there are two nipples, one midway between the fore and hind leg, and the other midway between this and the base of the fore leg. In the coypu, a creature often carrying its young on its back whilst it swims across rivers, the teats project from the flanks near the shoulders, and are of considerable length, so that the young readily reach them The *Insectivora* have, as a rule, more nipples than are found in any other order Thus in the tenrec (*Centetes*) there are as many as twenty two, and they are rarely fewer than fourteen, spread out in pairs from the pectoral to the inguinal regions There are ten teats in the common hedgehog, six to eight in moles and shrews, two in sloths and armadillos In *Cetacea* there are two long, narrow, flat glands lying between the dermal and abdominal muscles, with the subcutaneous blubber separating them from the skin The peculiarity of the arrangement in these animals, where suckling is performed under water, is the large size of the central duct, which acts as a kind of reservoir, so that the young may obtain a considerable supply in a very short time It would appear also that when suckling takes place the nose of the young is above the surface of the water Among Ungulates, in the elephant the glands and teats are between the fore legs, in the rhinoceros they are inguinal, in the mare and ass the glands are two in number, and are found between the thighs, about 9 inches in front of the vulva, the tapir has two inguinal nipples, the peccary two ventral and two inguinal, the wild sow eight nipples, whilst in the domestic breeds there are at least ten, extending from the pectoral to the inguinal regions Ruminants have the glands aggregated into a round mass in the inguinal region, pendulous in full function, divisible into two glands, each of which has a large reservoir When in use the teats, one pair or two pairs being the number, in connexion with the reservoirs become so large as to receive the special name of "udder All the deer tribe, camels, the giraffe, and all kinds of cows have four teats most antelopes and the gazelles have two teats, whilst a few antelopes have four As to *Carnivora*, the felines have usually six nipples, the wolf jackal, fox, dog have usually eight, the seals and the walrus have four, the otters two, the weasels six the bears six, and in the kinkajou (*Cercoleptes*) the number is reduced to two Amongst *Quadrumana*, the aye aye (*Chiromys*) has only one pair of nipples, about an inch and a half in front of the vulva, many lemurs have in addition to those a pectoral pair, in all the platyrhine and catarhine *Quadrumana* there is only one pair of glands, restricted to the pectoral region Here the teats are between the fore legs, and the young clings to the mother s breast in human fashion, but there is no protrusion of the breast as in the human being (For further details see Owen s *Anatomy of Vertebrates*, vol iii p 769)

In the human race the glands are two in number, forming, along with the skin and fat, two rounded eminences, one on each side, on the front of the thorax. They extend from the third to the sixth or seventh rib, and from the side of the sternum to the axilla In the centre projects a small conical body, the *nipple* Around the nipple is a coloured circle, or *areola*, which is darker during pregnancy, and even in women who have borne children than in the virgin state The surface of the nipple is wrinkled, and with a magnifying glass is seen to be covered with papillæ It is perforated by numerous openings, the mouths of the milk ducts The tissue of the nipple contains numerous minute blood vessels, and it has at the base muscular fibres arranged in concentric circles and in radiating bands It has much of the character of erectile tissue, as in the *corpora cavernosa* of the penis, becoming turgid, firm, and prominent from excitement The base of the gland lies on the pectoral muscle, a thin layer of fascia intervening The surface is covered with fat, which gives it the smooth rounded outline It is amply supplied with blood by the long thoracic artery, some other minute branches of the axillary artery, the internal intercostal artery, and the subjacent intercostals The nerves come from the anterior and middle intercostal cutaneous branches, and the nipple is especially sensitive The gland is composed of numerous lobes bound together by connective and adipose tissue, and each lobe is formed of smaller lobules Each lobe has an excretory duct, and these ducts, from fifteen to twenty in number, converge towards the areola, beneath which they are dilated so as to form sinuses from ⅛th to ¼th of an inch in calibre From these sinuses arise the ducts which open on the surface of the nipple The general structure will be understood by referring to the accompanying figures, along with the description

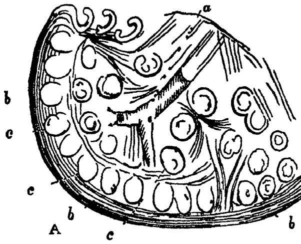


FIG 1—Half-diagrammatic view of a section through a lobule of the mammary gland after Klein (*Atlas of Histology* plate xl fig 1) magnified 45 diameters *a* a duct dividing into two branches *b b b* connective tissue surrounding and going between the ultimate pouches of the gland *c c c* the pouches or *alveoli* of the gland the dots representing the cells lining them

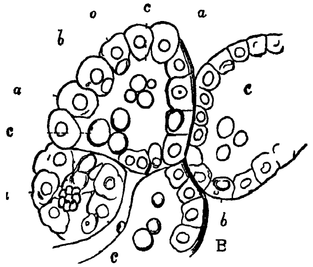


FIG 2—A portion of the same gland magnified about 400 diameters showing one complete and two incomplete alveoli *a a a* short columnar epithelial cells lining the alveolus each having an oval or rounded nucleus *b b b* epithelium cells containing next the interior of the alveolus a milk globule *c c c c* milk globules which have been set free from epithelial cells

When a duct is traced into the gland, it is found to subdivide into smaller ducts, and these into still smaller, until the smallest ductlet is reached, round the end of which are clustered several *alveoli* or pouches Each alveolus has a wall, lined with epithelium cells In the wall of the alveolus there are capillary blood vessels which bring the blood near the cells By this blood the cells are nourished There is a minute cavity in the centre of each alveolus into which cells or their products can accumulate There can be no doubt that the formation of the milk globule takes place in these cells Whilst milk is not being formed the cells have a granular appearance, and the lumen or central cavity of the alveolus is small, but during secretion the cavity is enlarged and shows a few milk globules, whilst one or more milk globules can be seen in the interior of the cell If the milk globule in the cell be very large, the nucleus of the cell is pressed outwards and the protoplasm of the cell is reduced to a thin covering, over the globule, at this stage presenting a striking resemblance to a fat cell containing an oil globule Thus each milk globule is formed in the protoplasm of the epithelium cell, and even at an early stage each milk globule consists of a minute drop of fat or oil surrounded by a thin albuminous envelope It has not been clearly ascertained whether epithelial cells, after having secreted milk globules, degenerate and fall off, or whether they have the power of ejecting the milk [illegible] The fluid constituents of milk (water holding salts in solution) may be separated from the blood by a kind of filtration under blood pressure, as is the case in other secretory processes The origin of the sugar of milk and of the casein is unknown (For a description of the minute structure of the milk gland, see Klein's *Atlas of Histology*, p 300, and references) At the beginning of lactation the milk is rich in large irregularly formed corpuscles (fig 3, *a*, *a*, *a*) called *colostrum* corpuscles These are contractile bodies, slowly changing their form and squeezing out the oily particles At first they are the only bodies present, but they are soon replaced by the ordinary milk globules Such globules have bright refractive edges, the surface is smooth, they vary in size from $\frac{1}{8000}$th to $\frac{1}{3000}$th of an inch in diameter, and each consists of a drop of fatty matter surrounded by a layer of albumen ("Ascherson s membrane")

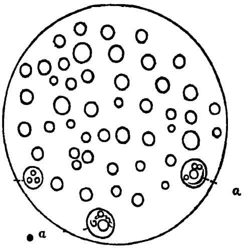


Fig 3—A drop of milk magnified 300 diameters *a a a colostrum* corpuscles

A secretion of milk takes place in newly born children, from the fourth to the eighth day, and also in rare cases in men (Hermann s *Physiology*, p 158) During gestation in the human being the mammary glands increase in size, immediately after the birth of the child active secretion commences, and usually it is on the stoppage of the secretion, ten months afterwards, that the process of menstruation, which has been arrested by impregnation, again is re established

The secretion of milk is undoubtedly affected by the nervous system, as is shown by fear or mental distress arresting or injuring the quality of the secretion, and by the "rush" or feeling of fulness in the breast experienced by the mother when the child s mouth touches the nipple, or even when she sees her offspring The nervous mechanism, however, is unknown, as it has been observed that secretion may continue even after section of all the nerves known to pass to the gland The nature of the diet has a marked influence on the quality of the secretion Thus the amount of casein and of fat is greater during an animal than during a vegetable diet Fatty foods do not seem to increase the amount of fat or butter, an ample supply of carbo hydrates (starches and sugars) increases the amount of sugar These facts indicate that most if not all of the constituents of milk are formed from changes in the protoplasm of the epithelial cells In some women the milk is deficient in fat and casein, and consequently is less nutritious Prolonged lactation diminishes the amount of fat and sugar without materially affecting the amount of albuminous matter, but the milk is less nutritious and is unfit for the child The occurrence of menstruation during lactation also deteriorates the milk (J G M)

Milk as Food

The milk of various domesticated animals is more or less used by man for food The milk of the cow, which may be taken as typical of all others, and is indeed by far the most important and valuable of all, is, when newly drawn, an opaque white fluid, with a yellowish tinge, soft, bland, and sweetish to the taste, and possessed of a faintly animal odour This odour, according to Schreiner, is due to the presence of sulphuretted hydrogen, and disappears after a short exposure The specific gravity of milk ordinarily ranges from 1 029 to 1 033, very seldom reaching 1 035 or falling so low as 1 027. In chemical constitution it consists of an emulsion of fatty globules (cream) in a watery alkaline solution of casein, and a variety of sugar, peculiar to milk, called lactose The fat (which when separated we know as butter) and the lactose constitute the carbonaceous portion of the milk regarded as food. The casein, which forms the principal constituent of cheese, and a certain proportion of albumen which is present, form the nitrogenous, while the complex saline substances and water are the mineral constituents These various substances are present in the proportions which render milk a perfect and typical food suitable to the wants of the young of the various animals for whom it is provided by nature The milk of all animals, so far as is known, contains them, although they are present in somewhat different proportions It is probable that the milk of ruminants possesses certain physical and physiological distinctions from that of non ruminant animals, which will account for the virtues attributed to the milk of the ass and mare The following table exhibits the chemical constitution of the kinds of milk most frequently used by man —

	Cow		Goat	Ewe [1]	Mare	Ass.	Human
	Winter Blyth	Cameron	Voelcker	Voelcker	Cameron	Chevallier and Henry	Gerber
Water	86 87	87 00	84 48	83 70	90 310	91 65	88 02
Fat	3 50	4 00	6 11	4 45	1 055	0 11	2 90
Casein and albumin	4 75	4 10	3 94	5 16	1 953	1 82	1 60
Sugar	4 00	4 28	4 68	5 73	6 285	6 08	7 03
Ash	0 70	0 62	0 79	0 96	0 369	0 34	0 31

In addition to these constituents milk contains small proportions of the gases carbonic acid, sulphuretted hydrogen, nitrogen, and oxygen, and minute quantities of other principles, the constant presence and essential conditions of which have not been determined These consist of galactin and lactochrome, substances peculiar to milk, discovered by Winter Blyth, with certain animal principles such as leucin, pepton, kreatin, tyrosin, &c The salts in milk consist, according to the average of numerous analyses by Fleischmann, of the following constituents —

Phosphoric acid	[illegible]	Potash	[illegible]
Chlorine	16 34	Magnesia	4 07
Lime	27 00	Ferric oxide	0 62
Soda	10 00		

Milk thus is not to be regarded as a definite chemical compound nor even as a mixture of bodies in fixed and invariable proportions Not only does the milk of different races and breeds of cows vary within comparatively wide limits, the milk of the same animal is subject to extensive fluctuation The principal causes of variation in the individual are age, period of lactation, nature and amount of food, state of health, and treatment, such as frequency of milking, &c The following table indicates the range of normal variations —

Water	90 00 to 83 65
Fat	2 80 ,, 4 50
Casein and albumin	3 30 ,, 5 55
Sugar	3 00 ,, 5 50
Ash	0 70 ,, 0 80

The average quantity of milk yielded by cows is also highly variable, both in individuals and breeds As a rule the smaller breeds of cows yield a small amount of milk rich in cream (butter fat), while the yield of the larger breed is greater in quantity, but comparatively deficient in cream A good milch cow should yield in a milk-giving period of from eight to nine months about

---

[1] Ewe's milk is exceedingly variable, especially in its percentage of fat. The above analysis is one of nine by Dr Voelcker, in which the fat was found to range from about 2 to 12¾ per cent

500 gallons of milk, from which nearly 500 ℔ of cheese or 200 ℔ of butter would be obtainable

Dairy Treatment —Cows are commonly milked by hand two or three times a day A milking machine of American origin, which was introduced about the year 1862, has been entirely abandoned The milk should be drawn from the animals in as clean a condition as possible, but notwithstanding every precaution some amount of hair and epithelial and other animal débris invariably enters the milk pail It has therefore to be immediately strained through a sieve with fine wire-cloth or hair strainer As milk is peculiarly susceptible of taint, and absorbs odours of all kinds with great avidity, it is of the utmost consequence that all vessels in which it is placed or kept should be so made as to be easily purified and that they should be kept scrupulously clean In Switzerland milk is strained with most beneficial effect through sprigs of washed fir tops, which inserted loosely and uprightly into the hole of a funnel arrest all hair, skin, clots, and slimy matter on the acicular leaves The milk drains through in a clean condition with a fresh slightly aromatized flavour favourable to its keeping A fresh sprig is used on each occasion of straining milk, so that there is freedom from the risk of taint which arises through the use of imperfectly cleaned wire gauze The milk must be removed from the cow house as quickly as possible, and, if intended for use as new milk and for sale in the neighbourhood of the dairy, it may at once be put up for delivery But if it has to travel a distance, or if it is to be kept for creaming or cheese making, it should be rapidly cooled down, and kept in a cool airy milk room if practicable, surrounded with fresh cold water

The ordinary method of separating cream either for direct use or for butter making is by allowing it to form on the surface and skimming it off with a broad flat spoon but ingenious adaptations of centrifugal machines—of which Laval's separator is one of the best known—have been introduced for the purpose of effecting the rapid and complete separation of the cream The centrifugal force of such machines throws the denser portions of the fluid towards the sides of a rapidly revolving cylinder, collecting the cream on an inner layer, which is carried off by one channel while the impoverished milk escapes by another The Laval separator gives very rich cream, as will be seen from the following analyses by Voelcker —

	Ordinary Cream	Cream by Separator	Skimmed Milk by Laval Separator	Ordinary Skimmed Milk
Water	77 30	66 12	90 82	89 25
Butter fat	15 45	27 69	0 31	1 12
Casein	3 40	2 69	3 31	3 69
Milk sugar	3 15	3 03	4 77	5 16
Mineral matter	0 70	0 47	0 79	0 78

After being kept some time, depending principally on the temperature at which it is maintained, milk begins to turn sour owing to the formation of lactic acid, by a process of fermentation, at the expense of the lactose or milk sugar The acid so developed causes a coagulation of the casein, and the milk separates into a solid white curd, and a thin transparent yellow milk serum or whey These changes can to a certain extent be artificially produced, hindered, and controlled The following are the results of analyses by Fleischmann —

Constituents of 100 *Parts of Sweet Milk*

3 56 butter
16 30 buttermilk.
0 14 loss
79 70 skimmed milk
7 93 curd
71 45 whey
0 32 loss
0 30 loss
0 30 loss

Relative Composition of Milk and its Products

	Water	Fat	Casein	Albumin.	Milk Sugar	Ash.
Whole milk	87 60	3 98	3 02	0 40	4 30	0 70
Cream	77 30	15 45	3 20	0 20	3 15	0 70
Skim milk	90 34	1 00	2 87	0 45	4 63	0 71
Butter	14 89	82 02	1 97	0 28	0 28	0 56
Buttermilk	91 00	0 80	3 50	0 20	3 80	0 70
Curd	59 30	6 43	24 22	3 53	5 01	1 51
Whey	94 00	0 35	0 40	0 40	4 55	0 60

The simplest and most advantageous form in which milk can be disposed of as a commercial product is by its sale as sweet or new milk, and it is in this manner that the greater proportion of the milk produced within the reach of large centres of population is disposed of New milk, cream, and skimmed milk are the only primary forms in which milk is sent into the market CHEESE and BUTTER have been dealt with in separate articles (*q v*) Whey, the yellow liquid remaining after the separation of the curd in cheese making, is a source of milk sugar, employed to a limited extent in pharmacy, but it is principally used for feeding pigs The buttermilk which remains after separating butter is a most wholesome and nutritious article of food

Preservation of Milk —The numerous methods which have been proposed for the preservation of milk in a condition fit for use over a lengthened period resolve themselves into (1) chemical treatment with alkaline salts and antiseptic bodies, (2) physical treatment, such as cooling or icing boiling and aeration and (3) condensation with or without the addition of a preservative agent All systems of preservation, however are subject to serious disadvantages either from their serving their purpose for too limited a time, or their interfering with the natural constitution and properties of the milk Of all preservatives cold is the most efficient and least objectionable It has been shown by Soxhlet (*Dingler s Polytech Journal* ccxxiii 329) that milk cooled by ice water remains sweet and unaltered for fourteen days but after that time acquires a rancid taste After twenty eight days it coagulates on boiling owing to the presence of acids resulting from the oxidation of the cream and in thirty four days it coagulates even in the ice water It is also found that milk which has undergone aeration with atmospheric air has its keeping properties much improved The aeration is effected by allowing the milk to fall from some height in a state of fine division by passing it through the meshes of a sieve By another method air cooled by passing over ice is blown through the milk

Milk keeps sweet for a longer time when boiled but the smell, taste, and other properties are affected partly owing to the escape of gases mixed with it when fresh The unpleasant flavour communicated by boiling can be avoided if the action takes place in a closed vessel and the milk is immediately cooled down in a refrigerator connected therewith In the case of any suspicion of taint in milk either from disease in the cow, contamination from unhealthy persons or the use of infected water in cleaning vessels, boiling is also strongly to be recommended, as it effectually destroys the germs of disease, in the carrying and spreading of which milk is a most active agent It is with the utmost difficulty that boiled milk can be coagulated by means of rennet, but by treatment with acid it coagulates more rapidly and freely than if unboiled

Of the various chemical compounds which have been suggested and more or less used for preserving milk, the most successful hitherto has been salicylic acid, which has the advantage of being tasteless and inodorous By briskly stirring in rather less than 2 grains to a pint of milk, it can be kept liquid and sweet in a temperature of from 65° to 68° Fahr for twelve hours, and at 55° Fahr for a whole day If 4 grains be used to a pint, coagulation in the higher temperature is delayed from two or three days, and at the lower temperature the milk may be kept good from three to five days Boracic acid and borax are also employed by dairymen, the former being known as glacialine salt The presence of any chemical antiseptic in milk is, however, at best a matter of doubtful advantage

Condensation —Milk is now treated on a large scale by a process of concentration, the product of which comes into the market in two forms—as "plain condensed milk and as "preserved milk." The credit of originating the industry is due to Mr Gail Borden of White Plains, New York, who began his experiments about 1849 In 1851 he introduced his plain condensed milk, which is simply milk from which between three fourths and four fifths of the water has been removed, and in 1861 he rendered important services to the army in the field by supplying preserved milk which was in effect milk similarly concentrated, with a proportion of sugar added, and hermetically sealed in tin cans The manufacture was transplanted to Switzerland in 1865, after which condensing factories were established in England, Ireland, Denmark, Bavaria, Norway, and elsewhere With the introduction of the condensing trade there has also been associated the factory system of dealing with dairy products, by which the milk of many dairies is carried to one centre and dealt with either for condensing or for cheese or butter making The following epitome of the process of condensing milk is from a paper by Mr Willard of Cornell university, New York (*Jour Roy Agric Soc*, 2d series, vol viii, 1872) The milk when received at the factory is first passed, he says, "through a strainer to the receiving vat, from this it is conducted off, going through another strainer into the heating cans, each holding about 20 gallons, these cans are set in hot water, and the milk is held in them till it reaches a temperature of 150° to 175° Fahr, it then goes through another strainer into a large vat, at the bottom of which is a coil of copper pipe, through which steam is conducted, and here the milk is heated up to the boiling point Then the best quality of white granulated sugar is added, in the proportion of 1¼ lb of sugar to the gallon of milk, when it is drawn into the vacuum pan having a capacity of condensing 3000 quarts or more at a time The milk remains in the vacuum pan subjected to steam for about three hours, during which time about 75 per cent of its bulk in water is removed, when it is drawn off into cans holding 40 quarts each The cans are only partially filled, and are then set in a large vat containing cold water, the water being of a height equal to that of the milk in the cans Here it is stirred until the temperature of the condensed fluid is reduced to a little below 70°, it is then turned into large drawing cans with faucets, in order to facilitate the filling of the small cans, holding 1 lb each, which are immediately soldered to exclude the air"

In the case of plain condensed milk the concentration is usually carried farther than is practised in preparing the preserved milk, it being evaporated down to between one fourth and one fifth of the original bulk It is not put up in sealed tins being intended for immediate use, and keeps sweet only for a few days varying with the state of the weather, whereas the sugared milk in sealed cans keeps for years The large amount, however, of cane sugar added to preserved milk seriously disturbs its balance of proportion as a perfect food and renders it unfit to be used alone in a dilute state as a substitute for mother's milk by infants a purpose for which it is largely employed It should also be observed that the relative proportion of fat is small, the milk being partially skimmed before it is operated on, so that the statement that preserved milk diluted with a small proportion of water is equal to cream is not to be relied on Preserved milk, rich in cream, has always a more or less rancid oily taste and cannot be obtained so sweet and even in flavour as that largely deprived of fat According to a German patent of E Klebs in Prague, plain condensed milk may be preserved by adding to every 100 litres of the original milk a solution of 50 grains of benzoate of magnesium in one litre of water

Adulteration —Practically the invariable mode of sophisticating milk for sale consists in the addition of water and in the subtraction of cream,—in other words, passing off skimmed or partly skimmed as new milk Now and again there are found certain little refinements on these simple frauds, such as adding a quantity of sugar to correct the specific gravity, flour or starch to increase opacity, and a touch of colouring matter to cover the bluish tinge which would betray skimmed milk In the United Kingdom no official standard of what constitutes pure milk has been promulgated, but the so called Somerset House standard has been generally recognized in law courts According to this, new milk should contain as a minimum of solids not fat 8 6 per cent and of fat 2 5 per cent, and of water a maximum of 88 9 per cent The most satisfactory manner of discovering the probable genuineness of a sample of milk is by chemical analysis carried sufficiently far to determine the amount of fat and of other solids present Numerous attempts have been made to place in the hands of dairymen, dealers, and consumers of milk a trustworthy method of estimating the condition and value of the article by simple quantitive tests for cream or fat—at once the most valuable constituent and one the presence of which in average proportion is indicative of the quality of the whole The simplest but at the same time the least trustworthy and efficient method is by means of the so-called "creamometer," which consists merely of a graduated glass tube in which a measured amount of milk is placed and the amount of cream it throws up is read off by means of the scale Specific gravity determinations have by themselves no significance, seeing milk deprived of its cream can by dilution with water be brought to correspond exactly with the original milk But by a combination of two methods,—first taking the specific gravity, next observing the yield of cream by the "creamometer," and finally taking the specific gravity of the milk deprived of cream, regard being had to the temperature of the milk in these observations, an approximately accurate idea of the value of a sample may be obtained. Among so called "lactoscopes," the operations of which are based on the fact that milk rich in cream is a much more opaque fluid than that from which cream has been taken or to which water is added, that invented by Professor Feser of Munich is one of the simplest and most useful It consists of a glass tube open at the upper end and attenuated at its lower extremity Into this narrower portion is fused a small cylindrical rod of opaque milk glass on which black lines are marked These lines are invisible when the lower portion of the tube is filled with a measured quantity of milk, but on addition of water they become visible When the black lines become by the gradual admixture of water perfectly distinct, the richness of the milk in cream globules is indicated by the height to which the mixture of milk and water has risen in the wide portion of the tube, which has engraved on it a scale showing on one side the amount of water added and on the other the proportion of cream equivalent to the transparency resulting from such addition

Statistics —In the year 1878 it was calculated by Mr J C Morton that the total yield of milk from the 2,250,000 cows and heifers in milk or in calf in England and Scotland amounted to about 1,000,000,000 gallons yearly He assumed that about one sixth of that quantity (167,000,000 gallons) went to feed calves and that the daily consumption of the population was 1,000,000 gallons, being rather more than a quarter of a pint per head, which accounts for 365,000,000, still leaving 468,000,000 gallons to be used for butter and cheese making Two thirds of this quantity, or 312,000,000 gallons, Mr Morton assumes was used for cheese making, yielding 2,800,000 cwts of cheese (rather less than 1 lb per gallon of milk), and the remainder, 156,000,000 gallons, of milk devoted to butter making would yield 530 000 lb of butter, or 1 lb of butter for every 21 pints of milk In these figures no account is taken of Ireland, whence at that period there were sent to England alone yearly 3 500 000 lb of salted butter In June 1882 the number of cows and heifers in milk and in calf in Great Britain did not vary greatly from the number on which Mr Morton's estimate for 1878 was based, being 2,267,175, whilst in Ireland the number was 1,398,905, making the total for the United Kingdom 3,682,317 If we take approximately Mr Morton's data as the basis of calculation, the 3,682,317 milk cows and heifers in the United Kingdom would yield, at 440 gallons per head, 1,620,219,480 gallons of milk Further, assuming that one sixth of this is consumed by calves, one third consumed by population, one third used for cheese making, and one sixth used for butter making, we have as the yield of cheese 4,846,000 cwts and as the yield of butter 920,000 cwts As Ireland is much more a butter producing than a cheese yielding country, the quantity of cheese made is probably overestimated in these figures, and the amount of butter made is correspondingly understated To bring out the consumption of dairy products for the year the following imports must be added —

Cheese	£4 742 868
Butter (including butt	11 339 226

Thus we find the total supply of cheese to the United Kingdom in 1882 was 6,538,495 cwts, and of butter the supply was 3,087,428 cwts Estimating the home produce of both articles at the same value as the imports, the cheese supply cost £18,320,000, and the butter £16,150,000 Adding to these the probable cost of the milk consumed as such (say 550 000,000 gallons at 1s per gallon = £27,500,000), we have for the year 1882 in round numbers £62,000,000 expended on dairy produce within the United Kingdom.

The total number of milch cows at present (1883) in the United States is stated at 15,000,000, which, taking the 440 gallons basis, yield annually 6,600,000,000 gallons, or nearly 30,000,000 tons of milk In America the factory system of treating milk has attained much greater dimensions than in Europe, and that perfection of treatment, combined with the cheapness of raising and feeding stock, enables the American companies to enter the European markets with large quantities of cheese and other dairy products of uniformly good quality which find a ready and remunerative sale

Koumiss —Under this name is properly understood a fermented drink prepared from mare's milk by the Tartar tribes of the Russian empire and by all the nomad races of the northern parts of Asia. It is made by diluting mare's milk with about one sixth part of its quantity of water, and adding as a ferment about one eighth part of very sour milk or of old koumiss. This mixture is placed in a wooden vessel which is covered over with a thick cloth, and so left for about twenty four hours in a moderately warm situation. During that time a thick coagulum rises to the surface, which is thoroughly reincorporated by churning After standing for another day, the whole mass is again thoroughly churned and mixed up, and in this state it forms new koumiss, having an agreeable subacid taste. The liquor is mostly stored and preserved by the Tartars in skin bottles, in which the fermentation continues developing its alcoholic qualities, and mellowing and improving its taste Genuine Tartar koumiss has the following composition —alcohol 3 21, lactic acid 0 19, sugar 2 10, albuminoids 1 86 fat 1·78, salts 0 509, carbonic acid 0 177, and water 93 46 A distilled spirit is prepared from koumiss, which is drunk among the Tartars under the name of araca or arsa Koumiss has of late years come into prominent notice as a remedial agent in cases of pulmonary consumption, and generally as a nutritious form of food easily assimilated by delicate stomachs It is probable that all its virtues reside in the original milk from which it is prepared in which case the koumiss can only be regarded as valuable in so far that it is a convenient form under which the essential properties of the milk can be preserved for use Under the name of koumiss a preparation of cow s milk is now very generally sold It is made by adding to each quart of new milk about a tablespoonful of common sugar and brewer s yeast, allowing the fermentation to proceed a sufficient length then bottling and corking as in the case of aerated waters Such a preparation contains about the same proportion of alcohol as genuine koumiss, but a non alcoholic variety can also be obtained made by a process of natural fermentation, which continuing after bottling develops a large amount of carbonic acid and renders the liquor highly effervescent (J PA)

MILL, JAMES (1773–1836), historian and political and mental philosopher, was born 6th April 1773, in the little village called Northwater Bridge (Bridge of North Esk), in the parish of Logie Pert, in the county of Forfar His father, James Mill, was a shoemaker, his mother, Isabel Fenton, belonged to a race of respectable farmers The father was industrious, good natured, and pious, but not known as specially intelligent The mother was of a proud disposition, and resolved to educate James, her eldest son, for a superior destiny He began his education at the parish school, and went on to the Montrose Academy, where he remained till the unusual age of seventeen and a half, when he went to the college of Edinburgh (1790) According to the usage of the time and neighbourhood, he ought to have been sent about thirteen or fourteen to Marischal College, Aberdeen His remaining so long at the Montrose Academy, and his going to Edinburgh for his university course, must be connected with his being taken up by Sir John and Lady Jane Stuart of Fettercairn, who engaged him to be tutor to their only daughter, known for having inspired the affection of Sir Walter Scott, and for being the mother of Principal James David Forbes Sir John and Lady Jane Stuart contracted a warm attachment for Mill, which lasted throughout their lives At Edinburgh University Mill was distinguished as a Greek scholar But he received his greatest impulse from Dugald Stewart, for whom he always expressed unbounded admiration In October 1798 he was licensed as a preacher, but seems to have preached very seldom His years from 1790 to 1802, besides being occupied with incessant studies extending into history and moral and political philosophy, were devoted to various tutorships

Failing to find a career to his mind in Scotland, in 1802 he went to London in company with Sir John Stuart, then member of parliament for Kincardineshire He soon obtained literary occupation to which he applied himself with untiring energy His first important venture was to start a periodical on a new plan, entitled *The Literary Journal*, which began to appear in January 1803, and continued under his editorship till the end of 1806 It was the most comprehensive in its aims of any periodical hitherto in existence, being a summary view of all the leading departments of human knowledge Thomas Thomson, the chemist, took charge of science, and many other men of ability co-operated Mill himself wrote largely in biography, history, political philosophy, political economy, and also in theology, on which his views at the time were broad without being sceptical The publisher of the journal was Baldwin, who was also the proprietor of the *St James's Chronicle*, a Conservative paper appearing three times a week For two or three years, from 1805 onwards, Mill was editor, but at last gave it up, partly on conscientious grounds, although in conducting it he never lent himself to the expression of any illiberal views, but often made it the vehicle of the opposite

In 1804 he wrote a pamphlet on the *Corn Trade*, advocating the impolicy of a bounty on the exportation of grain This was the beginning of his career as a political economist In 1805 he published a translation of Villers's work on the *Reformation*, an unsparing exposure of the vices of the papal system He added notes and quotations by way of confirmation of the author's views On this subject also he continued to hold strong opinions all through life, and often recurred to it in his articles in the reviews In 1805 he married Harriet Burrow, whose mother, a widow, kept an establishment for lunatics in Hoxton He then took a house in Rodney Street, Pentonville, where his eldest son, John Stuart, was born in 1806 It was about the end of 1806 that he entered upon the composition of the *History of India*, which he expected to finish in three or four years He was actually engaged upon it for twelve, giving, however, a considerable portion of his time to other writing for the support of his family The strain upon his energies for those years was enormous

He became acquainted with Jeremy Bentham in 1808, and was for many years Bentham's chief companion and ally In 1810 Bentham, to have Mill nearer him, gave him Milton's house, which adjoined his own, and was his property After a few months trial Mill had to give up this house on account of his wife's health, and went to live in Newington Green, but in 1814 Bentham leased the house No 1 Queen s Square, now 40 Queen Anne's Gate, close to his own garden, and gave it to Mill at a reduced rent, here he remained till 1831 The intimacy with Bentham was rendered still closer For four years, from 1814 to 1817, Bentham was at Ford Abbey, near Chard, in Somersetshire, and there Mill and his family were domesticated with him nine or ten months each year,—in which retirement it is probable that Mill was able to accelerate the completion of his history

In the twelve years between 1806 and 1818 he wrote a great many articles for various periodicals Among these were the *Anti Jacobin Review*, the *British Review*, and the *Eclectic Review*, but there is no means of tracing his contributions In 1808 he began to write for the *Edinburgh Review*, and contributed steadily till 1813, most of his articles being known In the *Annual Review* for 1808 two articles of his are traced—a "Review of Fox's History," and an article on "Bentham s Law Reforms," probably his first published notice of Bentham The first known article in the *Edinburgh* was on "Money and Exchange" (October 1808) In 1809 (January and July) he wrote at great length on Spanish America and General Miranda, with whom he was on terms of intimate friendship In the July number he also wrote on China In 1810 (April) he made a severe attack on the East India Company He also wrote on the liberty of the press and on the Church of England in connexion with the Lancasterian schools He was an active member of the committee for promoting education on Lancaster's plan In 1811 a periodical named the *Philanthropist* was started by William Allen, and published in quarterly numbers till 1817 Mill co-operated with Allen both in the writing and in the management He contributed largely to every number,—his principal topics being education, freedom of the press, and prison discipline (under which he expounded Bentham's "Panopticon") He made powerful onslaughts on the church in connexion with the Bell and Lancaster controversy. In 1814 Macvey Napier engaged him to contribute to the supplement to the fifth edition of the *Encyclopædia Britannica* Many of the articles became notable The list included "Government," "Jurisprudence," "Liberty of the Press," "Prisons and Prison Discipline," "Colony," "Law of Nations," "Education," "Beggar," "Benefit Societies," "Banks for Savings" In "Jurisprudence" and "Prisons" he was largely indebted to Bentham, in most of the others he was either altogether or in great part original The article on "Government" will occupy a permanent position in English history.

In 1818 was published the *History of India*, which had a great and speedy success It was the means of changing the author's future position The year following he was appointed an official in the India House, in the important department of the examiner of Indian correspondence He gradually rose in rank till he was appointed, in 1830, head of the office He introduced his eldest son into the same department in 1823

In 1824 Bentham projected the *Westminster Review*, and Mill was a principal writer for three years Some of his most vigorous writings are included among those contributions The first was an elaborate criticism of the *Edinburgh Review* as a whole, it was followed by an onslaught on the *Quarterly* Other articles dealt with English history and with ecclesiastical establishments, which he severely impugned To a periodical of short duration, *The Parliamentary History and Review*, he contributed an elaborate political retrospect of the parliament of 1820–26 In 1829 appeared the *Analysis of the Human Mind* From 1831 to 1833 he was largely occupied in the defence of the East India Company during the controversy attending the renewal of its charter, he being in virtue of his office the spokesman of the court of directors In 1834 Sir William Molesworth projected the *London Review*, and Mill contributed to it during the last two years of his life His most notable article was one entitled "The Church and its Reform," which was much too sceptical for the time, and injured the *Review* His last published book was the *Fragment on Mackintosh*, which appeared in 1835 He died on the 23d June 1836

A considerable space would be required to do justice to Mill's character—intellectual and moral—as shown both in his writings and in his intensely active and influential career He was an excellent scholar, in the sense of knowing the Greek and Roman classics His other accomplishments included general history, the philosophy of politics in the most comprehensive acceptation, logic, ethics, and mental philosophy The type of his intellect was logical in the highest degree, he was, above all things, clear and precise, an enemy of every form of looseness of reasoning, and a crusher of prevailing fallacies This is the most notable feature in his writings throughout His was also an original mind Except in a few subjects, which had been so well elaborated by Bentham that he was content to be little more than an expounder of Bentham's views, he gave a fresh turn to whatever topic he took up At a time when social subjects were subjected almost exclusively to an empirical handling he insisted on bringing first principles to bear at every point, in this lay both his strength and his weakness

His greatest literary monument is the *History of India* The materials for narrating the acquisition by England of its Indian empire were put into shape for the first time, a vast body of political theory was brought to bear on the delineation of the Hindu civilization, and the conduct of the actors in the successive stages of the conquest and administration of India was subjected to a severe criticism The work itself, and the author's official connexion with India for the last seventeen years of his life, effected a complete change in the whole system of governing that country

Mill played a great part as a politician and political philosopher in English affairs as well He was, more than any other man, the founder of what was called philosophical radicalism His writings on government and his personal influence among the Liberal politicians of his time determined the change of view from the French Revolution theories of the rights of man and the absolute equality of men to the claiming of securities for good government through a great extension of the electoral suffrage Under this banner it was that the Reform Bill was fought and won

His work on *Political Economy* was intended as a text book of the subject, and shows all the author's precision and lucidity It followed up the views of Ricardo, with whom Mill was in habitual intimacy. It urged strongly the modern application of the principle of population, and started the doctrine of taxing land for the unearned increment of value

By his *Analysis of the Mind* and his *Fragment on Mackintosh* Mill acquired a position in the history of psychology and ethics. Attached to the *a posteriori* school, he vindicated its claims with conspicuous ability. He took up the problems of mind very much after the fashion of the Scotch school, as then represented by Reid, Stewart, and Brown, but made a new start, due in part to Hartley, and still more to his own independent thinking He carried out the principle of association into the analysis of the complex emotional states, as the affections, the æsthetic emotions, and the moral sentiment, all which he endeavoured to resolve into pleasurable and painful sensations But the salient merit of the *Analysis* is the constant endeavour after precise definition of terms and clear statement of doctrines The *Fragment on Mackintosh* is a severe exposure of the flimsiness and misrepresentations of Mackintosh's famous dissertation on ethical philosophy It discusses, in a very thorough way, the foundations of ethics from the author's point of view of utility

Mill's influence on the young men of his time by his conversation has been especially celebrated Among those that came under this influence were some of the greatest names in the generation that succeeded him He had himself a very high ideal of public virtue, which he carried out, at the risk of sacrificing all his chances of worldly advancement, and he impressed this ideal on those that surrounded him,—most of all on his own son, who has since eclipsed his father in fame, if not in genius

See J S Mill's *Autobiography*, Bain's *Life of James Mill*, G S Bower's *Hartley and James Mill* (A. B *)

MILL, JOHN (*c* 1645–1707), editor of an historically important critical edition of the New Testament, was born about 1645 at Shap in Westmoreland, entered Queen's College, Oxford, as a servitor in 1661, and took his master's degree in 1669 Soon afterwards he was chosen fellow and tutor of his college, in 1676 he became chaplain to the bishop of Oxford, and in 1681 he obtained the rectory of Blechingdon, Oxfordshire, and was made chaplain to Charles II From 1685 till his death he held the appointment of principal of St Edmund's Hall, and in 1704 he was nominated by Queen Anne to a prebendal stall in Canterbury He died on June 23, 1707, just a fortnight after the publication of his Greek Testament

Mill's *Novum Testamentum Græcum, cum lectionibus variantibus MSS Exemplarium, Versionum, Editionum SS Patrum et Scriptorum Ecclesiasticorum, et in easdem notis* (Oxford, fol 1707), was undertaken by the advice and encouragement of Fell, his predecessor in the field of New Testament criticism, it represents the labour of thirty years and is admitted to mark a great advance on all that had previously been achieved The text indeed is that of R Stephanus (1550) but the notes, besides embodying all previously existing collections of various readings, add a vast number derived from his own examination of many new MSS and Oriental versions (the latter unfortunately he used only in the Latin translations) He was the first to notice, though only incidentally, the value of the concurrence of the Latin evidence with the Codex Alexandrinus, the only representative of an ancient non Western Greek text then sufficiently known, this hint was not lost on Bentley (see Westcott and Hort, *Introduction to New Testament*) Mill's various readings, numbering about thirty thousand, were attacked by Whitby in his *Examen* as destroying the validity of the text, Antony Collins also argued in the same sense though with a different object The latter called forth a reply from Bentley (*Phileleutherus Lipsiensis*) In 1710 Kuster reprinted Mill's Testament at Amsterdam with the readings of twelve additional MSS

MILL, JOHN STUART (1806–1873), son of JAMES MILL (*q v*), was born in London on the 20th May 1806 His education was from first to last undertaken by his father, and is likely long to remain a standing subject for wonder and discussion Much of the wonder is no doubt due to his father's monstrous inversion of custom, the boy being set almost as soon as he could speak to work at our time-honoured subjects of secondary and higher education He was taught the Greek alphabet at the age of three, and one of his earliest recollections, as he has recorded in his autobiography, was learning lists of common Greek words with their English meanings, written for him by his father on cards By his eighth year he had gone through in the original a great many Greek books "Of grammar," he says, "until some years later, I learnt no more than the inflexions of the nouns and verbs, but after a course of vocables proceeded at once to translation, and I faintly remember going through *Æsop's Fables*, the first Greek book which I read. The *Anabasis* which I remember better, was the second. I learnt no Latin until my eighth year. At that time I had read under my father's tuition a number of Greek prose authors, among whom I remember the whole of Herodotus and of Xenophon's *Cyropædia* and *Memorials of Socrates*, some of the lives of the philosophers by Diogenes Laertius, part of Lucian, and Isocrates *Ad Demonicum* and *Ad Nicoclem*. I also read, in 1813, the first six dialogues (in the common arrangement) of Plato, from the *Euthyphron* to the *Theætetus* inclusive." Besides all these Greek books, he had read a great deal of history in English—Robertson's histories, Hume, Gibbon, Watson's *Philip II and III*, Hooke's *Roman History*, Rollin's *Ancient History*, Langhorne's *Plutarch*, Burnet's *History of My Own Times*, thirty volumes of the *Annual Register*, Millar's *Historical View of the English Government*, Mosheim's *Ecclesiastical History*, M'Crie's *Knox*, and two histories of the Quakers.

That Mill "knew Greek" and "read Plato" before he was eight years old is often repeated, sometimes as an instance of amazing precocity, sometimes as an awful example of injudicious parental forcing. The astonishment that a child should have done so much at such an age is probably as little grounded in reason as was Mill's own opinion that any child might have done the same. It is forgotten that many thousands of persons have known Greek before the age of eight without a knowledge of the technicalities of Greek grammar. In presence of the fact that Mill was never distinguished for great memory of detail or richness of historical or literary allusion, it is a fair conclusion that the matter of his reading at this age was of as little service to him in after life as if he had read the trashiest of boy's own books. This is not to say that for educational purposes his early years were wasted as in his own and his father's opinion they generally are. But undoubtedly the main factor in Mill's education was not the literature put into his hands, but his constant intercourse with the active richly stored mind and strenuous character of his father. If any should be tempted to imitate the method, they should bear in mind that this was the cardinal element of it. The tutor was of more importance than the books. The reading of Plato's dialogues would have been only an exercise in rough translation if the boy had not had a Socrates with him in living communion. The child was a constant inmate of his father's study, and trotted by his side in his walks, giving from jottings on slips of paper as good an account as he could of what he had read. He thus learnt at an unusually early age by example, precept, and practice the habit of strenuous application to difficult work. The fact that Mill was taught thus early to take his chief pleasure in overcoming intellectual difficulties, and to realize the meaning of general terms, accounts for the singular and altogether unparalleled ease which he acquired in the treatment of political and social generalizations, not in barren abstract vagueness, but in close relation with facts. This on the intellectual side; and on the moral side the child was almost from the dawn of consciousness instructed to regard himself as consecrated to a life of labour for the public good; his ambition was kindled to follow in the footsteps of the great men of all ages, and at the same time the utmost care was taken to purify that ambition from unworthy motives.

A contemporary record of Mill's studies from eight to thirteen is published in Dr Bain's sketch of his life. It shows that the *Autobiography* rather understates than overstates the amount of work done. At the age of eight he began Latin, Euclid, and algebra, and was appointed schoolmaster to the younger children of the family—a post, he hints, more serviceable to his intellect than to his manners. His main reading was still history, but he went through all the Latin and Greek authors commonly read in the schools and universities, besides several that are not commonly read by undergraduates. He was not taught to compose either in Latin or in Greek, and he was never an exact scholar in the academic sense; it was for the subject-matter that he was required to read, and by the age of ten he could read Plato and Demosthenes with ease. His father's *History of India* was published in 1818; immediately thereafter, about the age of twelve, John, under his energetic direction, began a thorough study of the scholastic logic, at the same time reading Aristotle's logical treatises in the original. In the following year he was introduced to political economy. And there, when the pupil was nearly fourteen, this remarkable education terminated. From that time he worked less immediately under his father's eye. It was an inevitable incident of such an education that Mill should acquire many of his father's speculative opinions, and his father's way of defending them. But his mind did not receive the impress passively and mechanically. "One of the grand objects of education," according to the elder Mill, "should be to generate a constant and anxious concern about evidence"; and he laboured with all the energy of his strong will against allowing his son to become a parrot of his own opinions and arguments. The duty of collecting and weighing evidence for himself was at every turn impressed upon the boy; he was taught to accept no opinion upon authority; he was soundly rated if he could not give a reason for his beliefs. John Stuart Mill was deliberately educated as an apostle, but it was as an apostle of reasoned truth in human affairs, not as an apostle of any system of dogmatic tenets. It was purposely to prevent any falling off from this high moral standard till it should become part of his being that his father kept the boy so closely with himself. Much pity has been expressed over the dreary cheerless existence that the child must have led, cut off from all boyish amusements and companionship, working day after day on his father's treadmill; but a childhood and boyhood spent in the daily enlargement of knowledge, with the continual satisfaction of difficulties conquered, buoyed up by day-dreams of emulating the greatest of human benefactors, need not have been an unhappy childhood, and Mill expressly says that his was not unhappy. It seems unhappy only when we compare it with the desires of childhood left more to itself, and when we decline to imagine its peculiar enjoyments and aspirations. Mill complains that his father often required more than could reasonably be expected of him, but his tasks were not so severe as to prevent him from growing up a healthy, hardy, and high spirited boy, though he was not constitutionally robust, and his tastes and pursuits were so different from those of other boys of the same age.

Most of Mill's fifteenth year was spent in France in the family of Sir Samuel Bentham. Away from his father, he maintained his laborious habits; the discipline held. Copious extracts from a diary kept by him at this time are given by Dr Bain, and show how methodically and incessantly he read and wrote, studied botany, tackled advanced mathematical problems, made notes on the scenery and the people and customs of the country. On his return in 1821 he continued his old studies with the addition of some new ones. One of the new studies was Roman law, which he read with John Austin, his father having half decided on the bar as the best profession open to him. Another was psychology. In 1823, when he had just completed his seventeenth year, the notion of the bar as a livelihood was abandoned, and he entered as a clerk in the examiner's office of the India House, "with the understanding that he should be employed from the beginning in preparing drafts of despatches, and be thus trained up as a successor to those who then filled the highest departments of the office."

Mill's work at the India House, which was henceforth his livelihood, did not come before the public, and those who have scouted his political writings as the work of an abstract philosopher, entirely unacquainted with affairs, have ignored the nature of his duties. From the first he was more than a clerk, and after a short apprenticeship he was promoted, in 1828, to the responsible position of assistant-examiner. The duty of the so-called examiners was to examine the letters of the agents of the Company in India, and to draft instructions in reply. The character of the Company's government was almost entirely dependent upon their abilities as statesmen. For twenty years, from 1836 to 1856, Mill had charge of the Company's relations with the native states. In the hundreds of despatches that he wrote in this capacity, much, no doubt, was done in accordance with established routine, but few statesmen of his generation had a wider experience of the responsible application of principles of government to actual emergencies. That he said so little about this work in the *Autobiography* was probably because his main concern there was to expound the influences that affected his moral and mental development. A man of different temperament might have found abundance of dramatic interest in watching the personal and political changes in so many distinct states. But Mill makes no reminiscences of this kind, nor does he give any clue to the results of his own initiative.

To return to his extra-official activity, which received an immense impulse about the time of his entering the India House from what must strike a man of the world as a strange source. The reading of Dumont's exposition of Bentham's doctrines in the *Traite de Legislation* was an epoch in Mill's life. It awoke in him an ambition as enthusiastic and impassioned as a young man's first love. The language that he uses about it in his autobiography reveals a warmth of inner life that few people would suspect from the record of his dry studies. When he laid down the last volume, he says, he had become a different being. It gave unity to the detached and fragmentary component parts of his knowledge and beliefs. "I now had opinions—a creed, a doctrine, a philosophy—in one among the best senses of the word, a religion, the inculcation and diffusion of which could be made the principal outward purpose of a life. And I had a grand conception laid before me of changes to be effected in the condition of mankind through that doctrine." He had been carefully bred to contemplate work for human welfare as the ruling motive of his life; that motive had now received definite direction.

Many a youth has entered the world with ambition equally high, but few have felt as Mill felt the first shock of despair, and fewer still have rallied from that despair with such indomitable resolution. The main secret of the great "crisis" of his youthful life is probably to be found in the lofty ardour of the aspirations then conceived and shaped. For four years he worked with faith and hope in his mission, and these were years of incessant propagandist activity. The enthusiast of seventeen, burning to reorganize human affairs so as to secure the greatest happiness of the greatest number, set siege to the public mind through several approaches. He constituted a few of his youthful friends, imbued with the principles of his new creed, into a society which he called the "Utilitarian" Society, taking the word, as he tells us, from one of Galt's novels. Two newspapers were open to him—the *Traveller*, edited by a friend of Bentham's, and the *Chronicle*, edited by his father's friend Black. One of his first efforts was a solid argument for freedom of discussion, in a series of letters to the *Chronicle* apropos of the prosecution of Richard Carlile. But he watched all public incidents with a vigilant eye, and seized every passing opportunity of exposing departures from sound principle in parliament and courts of justice. Another outlet was opened up for him in 1824 by the starting of the *Westminster Review*, and still another in the following year in the *Parliamentary History and Review*. This year also he found a congenial occupation in editing Bentham's *Rationale of Judicial Evidence*. Into this he threw himself with zeal. And all the time, his mind full of public questions, he discussed and argued eagerly with the many men of promise and distinction who came to his father's house. He engaged in set discussions at a reading society formed at Grote's house in 1825, and in set debates at a Speculative Society formed in the same year.

"A very disquisitive youth," was Peacock's description of young Mill at this period, and this was probably how the enthusiast struck most of his outside acquaintances. But the glow of a great ambition as well as the energy of a piercing intellect might have been felt in his writings. His mission was none the less arduous that he proposed to convert the world by reason. Only the fulness of unbroken hope could have supported his powers, if he had had a frame of iron, under the strain of such incessant labour. All of a sudden, a misgiving which he compares to the Methodist's "first conviction of sin" made a rift in the wholeness of his faith in his mission. "It was in the autumn of 1826. I was in a dull state of nerves, such as everybody is occasionally liable to; unsusceptible to enjoyment or pleasurable excitement; one of those moods when what is pleasure at other times becomes insipid or indifferent. . . . In this frame of mind it occurred to me to put the question directly to myself, 'Suppose that all your objects in life were realized, that all the changes in institutions and opinions which you are now looking forward to could be completely effected at this very instant, would this be a great joy and happiness to you?' And an irrepressible self-consciousness distinctly answered, 'No!' At this my heart sank within me; the whole foundation on which my life was constructed fell down. All my happiness was to have been found in the continual pursuit of this end. The end had ceased to charm, and how could there ever again be any interest in the means? I seemed to have nothing left to live for."

The passage in his autobiography in which Mill gives an account of this prostrating disenchantment and his gradual release from its benumbing spell is one of the most interesting chapters in personal history. The first break in the gloom came, he tells us, from his reading in Marmontel's *Memoires* "the passage which relates his father's death, the distressed position of the family, and the sudden inspiration by which he, then a mere boy, felt and made them feel that he would be everything to them—would supply the place of all that they had lost." Mill was moved to tears by the narrative, and his burden grew lighter at the thought that all feeling was not dead within him, that he was not a mere intellectual machine. This incident, and the delight that he now began to take in Wordsworth's "Poems founded on the Affections," gives a clue to one of the secrets of Mill's despondency. It was an unsatisfied longing for personal affection, for love and friendship, of which his life hitherto had been barren. His father seems to have been reserved, undemonstrative even to the pitch of chilling sternness in his intercourse with his family; and among young Mill's comrades contempt of feeling was almost a watchword, because it is so often associated with mischievous prejudice and wrong conduct. Himself absorbed in abstract questions and projects of general philanthropy, he had been careless of winning or keeping personal attachment. But it was not till despair first seized him, as he looked back at the poverty of the results of his work as an apostle, that Mill began to feel the void in his affections and the need of human sympathy. We must remember how little when his ambition was formed he knew of the living world around him. He knew in terms that political and social change must be slow; he could whisper patience to himself, and say to himself that his life must be happy because the attainment of his great object must occupy the whole of it; but without experience he could not have been prepared for the actual slowness of the reformer's work, or armed against its terribly oppressive influence. Inevitably he underrated the stolidity and strength of the forces arrayed against him. Four years seems a long time at that age. In 1826 Mill could look back to four years of eager toil. What were the results? He had become convinced that his comrades in the Utilitarian Society, who never numbered more than ten, had not the stuff in them for a world-shaking propaganda; the society itself was dissolved; the *Parliamentary Review* was a failure; the *Westminster* did not pay its expenses; Bentham's *Judicial Evidence* produced little effect on the reviewers. His own reception at the Speculative Debating Society, where he first measured his strength in public conflict, was calculated to produce self-distrust. He found himself looked upon with curiosity as a precocious phenomenon, a "made man," an intellectual machine set to grind certain tunes. The most clear and cogent reasoning failed to sway his audience. Great things had been expected of this society as a means of bringing together for close discussion the leading young men then in public life or looking forward to it. Its first session proved a fiasco. The leaders that had been expected stayed away. With these repulses to his hopes along the whole line of his activity, Mill must also have suffered from the nervous exhaustion that only the hope and heat of the fight had kept him from feeling before. No wonder that he was disheartened, began to feel defects in his father's training, to question and analyse his own faith, to yearn for the solace of personal affection, and to reconstitute his scheme of life.

That in spite of this rude shock the foundations laid by his early training remained stable appears from the facts that all through the period of his gloom he continued working as before, and that he considered himself bound, once convinced that his old plan of life was insufficient, to build up a thoroughly reasoned new plan wherewith to give new heart and hope to his work. The new system was much less different from the old than might be supposed from what he says of the struggle that it cost him to reach it. Regard for the public good was still his religion, the ruling motive that gave unity to his conduct. But he now recognized that this was too vague and insubstantial an object to be sufficient of itself for the satisfaction of a man's affections. It is a proof of the dominating force of his father's character that it cost the younger Mill such an effort to shake off his stern creed about poetry and personal emotion. Like Plato, the elder Mill would have put poets under ban as ministers of prejudice and enemies of truth. And he often insisted on the wisdom of restricting as much as possible the private affections, while expanding as much as possible the public affections. Landor's maxim of "few acquaintances, fewer friends, no familiarities" had his cordial approval. These doctrines the younger Mill at first took up with boyish enthusiasm and pedantry, but it was against this part of his father's creed that he now felt himself forced in reason to revolt. He stood too much in awe of his father to make him the confidant of his difficulties. He wrestled with them in the gloomy solitude of his own mind. He was victorious; he reached firm ground at last; but the struggle left him in several respects changed. He carried out of the struggle as the fruits of victory a more catholic view of the elements of human happiness, a delight in the poetry of nature and the affections as well as the poetry of heroic unselfish character and action, a disposition to study more sympathetically the point of view of opponents, a more courteous style of polemic, a hatred of sectarianism, an ambition no less noble and disinterested but moderated to practical possibilities.

In the course of the next few years Mill wrote comparatively little, but he "carried on," as he says, "a quantity of thinking respecting a host of subjects." It was a period of search, deliberation, germination, and striking root. Coincident if not causally connected with the relief from his spiritual crisis came his first consciousness of power as "an original and independent thinker." In the dialectic conversations with a small band of students at Grote's house, he regained the self-confidence that had been shaken in the larger and rougher arena of the Speculative Debating Society. The beginning of his works on logic and political economy may be traced back to those discussions, and he learnt from them, he tells us, the habit of "never accepting half solutions of difficulties as complete; never abandoning a puzzle, but again and again returning to it until it was cleared up; never allowing obscure corners of a subject to remain unexplored, because they did not appear important; never thinking that he perfectly understood any part of a subject until he understood the whole." He learnt also an important moral lesson from the Speculative Society, besides learning the strong points of other political and social creeds and the weak points of Benthamism from defending it point by point against all comers. With all his despondency, he did not abandon the meetings of the society after the fiasco of the first session. He stood by it firmly, and in a short time had the triumph of seeing its debates famous enough to attract men with whom it was profitable for him to interchange opinions, among others Maurice and Sterling. He ceased to attend the society in 1829, but he carried away from it the strengthening memory of failure overcome by persevering effort, and the important doctrinal conviction that a true system of political philosophy was "something much more complex and many-sided than he had previously had any idea of, and that its office was to supply, not a set of model institutions, but principles from which the institutions suitable to any given circumstances might be deduced."

The first sketch of Mill's political philosophy appeared in a series of contributions to the *Examiner* in the autumn of 1830 on "Prospects in France." He was in Paris soon after the July Revolution, made the acquaintance of the leading spirits among the younger men, and in his discussion of what they were doing and what they should do in making a new constitution we find the germs of many thoughts afterwards more fully developed in his *Representative Government*.

The division of a man's life into periods must always be a rough partition, but we may conveniently and with tolerable accuracy take these letters as marking the close of his period of meditative search, of radication, and his return to hopeful aspiring activity. It was characteristic of the nature of the man that he should be stirred to such delight by the Revolution in France, and should labour so earnestly to make his countrymen understand with what gravity and sobriety it had been effected. Their own Reform Bill came soon after, and it is again characteristic of Mill—at once of his enthusiasm and of his steady determination to do for humanity the work that nobody else seemed able or willing to do—that we find him in the heat of the struggle in 1831 writing to the *Examiner* a series of letters on "The Spirit of the Age" which drew from Carlyle the exclamation, "Here is a new mystic!" We can easily see now what it was in these remarkable essays that fascinated Carlyle, it was the pervading opinion that in every natural state of society power must be in the hands of the wisest. This was the condition of stability, when power and wisdom ceased to coincide, there was a disturbance of the equilibrium till this coincidence was again effected. But whether Carlyle was right in the epithet "mystic" may be judged from the fact that Mill's inductive logic was the direct result of his aspirations after political stability as determined by the dominion of the wisest. "Why is it," he asked, "that the multitude accept implicitly the decisions of the wisest, of the specially skilled, in physical science?" Because in physical science there is all but complete agreement in opinion. "And why this agreement?" Because all accept the same methods of investigation, the same tests of truth. Is it possible then to obtain unanimity as to the methods of arriving at conclusions in social and political matters, so as to secure similar agreement of opinion among the specially skilled, and similar general respect for their authority? The same thought appears in a review of Herschel's *Natural Philosophy*, written about the same time. Mill remarks that the uncertainty hanging over the very elements of moral and social philosophy proves that the means of arriving at the truth in those sciences are not yet properly understood. "And whither," he adds, "can mankind so advantageously turn, in order to learn the proper means, and to form their minds to the proper habits, as to that branch of knowledge in which by universal acknowledgment the greatest number of truths have been ascertained, and the greatest possible degree of certainty arrived at?"

By 1831 Mill's enthusiasm for humanity had been thoroughly reawakened, and had taken the definite shape of an aspiration to supply an unimpeachable method of search for conclusions in moral and social science. From the platform on which Carlyle and Mill met in 1831 they travelled different roads,—the one to preach the duty of obedience to the wisest, the other to search for a means by which wisdom might be acquired such as would command respect and win the assent of free conviction. No mystic ever worked with warmer zeal than Mill. But his zeal encountered a check which baffled him for several years, and which left its mark in various inconsistencies and incoherences in his completed system. He had been bred by his father in a great veneration for the syllogistic logic as an antidote against confused thinking. He attributed to his early discipline in this logic an impatience of vague language which in all likelihood was really fostered in him by his study of the Platonic dialogues and of Bentham, for he always had in himself more of Plato's fertile ingenuity in canvassing the meaning of vague terms than the schoolman's rigid consistency in the use of them. Be this as it may, enthusiastic as he was for a new logic that might give certainty to moral and social conclusions, Mill was no less resolute that the new logic should stand in no antagonism to the old. In his *Westminster* review of Whately's *Logic* in 1828 (invaluable to all students of the genesis of Mill's logic) he appears, curiously enough, as an ardent and brilliant champion of the syllogistic logic against highfliers such as the Scotch philosophers who talk of "superseding" it by "a supposed system of inductive logic." His inductive logic must "supplement and not supersede." It must be concatenated with the syllogistic logic, the two to be incorporated in one system. But for several years he searched in vain for the means of concatenation.

Meantime, while recurring again and again, as was his custom, to this cardinal difficulty, Mill worked indefatigably in other directions where he saw his way clear, expatiating over a wide range of political, social, economical, and philosophical questions. The working of the new order in France, and the personalities of the leading men, had a profound interest for him, he wrote on the subject in the *Examiner*. He had ceased to write for the *Westminster* in 1828, but during the years 1832 and 1833 he contributed many essays to *Tait's Magazine*, the *Jurist*, and the *Monthly Repository*. In 1835 the *London Review* was started, with Mill as editor, it was amalgamated with the *Westminster* in 1836, and Mill continued editor till 1840. Much of what he wrote then was subsequently incorporated in his systematic works, some of his essays were reprinted in his first two volumes of *Dissertations and Discussions* (1859). The essays on Bentham and Coleridge constituted the first manifesto of the new spirit which Mill sought to breathe into English Radicalism. But the reprinted papers give no just idea of the immense range of Mill's energy at this time. His position in the India Office, where alone he did work enough for most men, cut him off from entering parliament; but he laboured hard though ineffectually to influence the legislature from without by combating the disposition to rest and be thankful. In his *Autobiography* he admits that the attempt to form a Radical party in parliament at that time was chimerical.

It was in 1837, on reading Whewell's *Inductive Sciences* and re-reading Herschel, that Mill at last saw his way clear both to formulating the methods of scientific investigation and joining on the new logic as a supplement to the old. Epoch-making as his logic undoubtedly was, from the multitude of new views opened up, from the addition of a new wing to the rambling old building and from the inspiring force with which every dusty chamber was searched into and illuminated, Mill did not escape all the innumerable pitfalls of language that beset the pioneer in such a subject. It is evident from a study of his purposes and the books from which he started that his worst perplexities were due to his determination to exhibit scientific method as the complement of scholastic logic. In his defence of the syllogism he confounds the syllogistic forms with deductive reasoning. Every deductive reasoning may be thrown into the form of a syllogism, but not every syllogism is deductive. The reasoning in several of the syllogistic forms is not deductive at all in the sense of involving a movement from general to particular. Although he knew Aristotle in the original, Mill did not recognize the fact that the syllogistic machinery was primarily constructed for the reasoning together of terms. As regards the word induction, Mill uses it in different connexions to cover three or four distinguishable meanings—induction viewed as the establishment of predications about a general term, induction viewed as inference from the known to the unknown, induction viewed as verification by experiment, and induction viewed as the proof of propositions of causation. The form of his system was really governed by the scholastic notion of induction as a means of establishing general propositions; the inductive part of his system is introduced after the deductive under this character; while the greater portion of the substance of what he treats of under the name of induction, and especially the so-called experimental methods, have nothing whatever to do with the establishment of general propositions, in the technical sense of general propositions.

But the permanent value and influence of Mill's inductive logic is not to be measured by technical inaccuracies and inconsistencies, to which an academic mind may easily attach undue importance. In the technical history of the science, Mill's *Logic* may be viewed as an attempt to fuse the practical tests of truth set forth in Herschel's *Discourse on Natural Philosophy* with the theoretic views of induction propounded in Whately's *Logic* But in the history of thought the great importance of the work is due not so much to its endeavour to formulate the methods of science and lay bare the first principles on which they rest as to its systematic application of scientific method to what he called the moral sciences Mill has often been criticized as if he had pretended to teach men how to conduct their investigations and how to make discoveries in the physical sciences His work was rather to educe from the practice of men of science the principles on which they proceed in testing and proving their speculations concerning cause and effect in the physical world, and see whether the same principles could not be applied in testing and proving speculations concerning cause and effect in the moral world What is the effect upon human character and human happiness of given social and physical conditions—climate, institutions, customs, laws? How can conclusions upon such points be proved? These were the questions in which Mill was interested, and the striking novelty of his work was its endeavour to show that propositions of cause and effect in human affairs must be proved, if they admit of proof at all, absolute or approximate, on the same principles with propositions of cause and effect in the material world

The *Logic* was published in 1843 In 1844 appeared his *Essays on Some Unsettled Questions in Political Economy* These essays were worked out and written many years before, and show Mill in his first stage as a political economist Four out of the five essays are elaborate and powerful solutions of perplexing technical problems—the distribution of the gains of international commerce, the influence of consumption on production, the definition of productive and unproductive labour, the precise relations between profits and wages Though Mill appears here purely as the disciple of Ricardo, striving after more precise statement, and reaching forward to further consequences, we can well understand in reading these essays, searching, luminous large and bold in outline, firmly wrought in detail, how about the time when he first sketched them he began to be conscious of power as an original and independent thinker

That originality and independence became more conspicuous when he reached his second stage as a political economist, struggling forward towards the standpoint from which his systematic work was written It would seem that in his fits of despondency one of the thoughts that sat upon him like a nightmare and marred his dreams of human improvement was the apparently inexorable character of economic laws, condemning thousands of labourers to a cramped and miserable existence, and thousands more to semi starvation From this oppressive feeling he found relief in the thought set forth in the opening of the second book of his *Political Economy* —that, while the conditions of production have the necessity of physical laws, the distribution of what is produced among the various classes of producers is a matter of human arrangement, dependent upon alterable customs and institutions There can be little doubt that this thought, whether or not in the clear shape that it afterwards assumed, was the germ of all that is most distinctive in his system of political economy It was as far as possible from the rigidity of his method of exposition to fall into the confusion of supposing that it was for political economy to discuss the equity of different modes of distribution, or the value of other objects of human endeavour conflicting with the production of wealth, but he put economic inquiries clearly in their proper place as leading to conclusions that were not always final and binding on the practical statesman, but had to be taken with other considerations as governing rational human action. Besides thus putting political economy in its just correlation with other parts of social science and conduct, Mill widened the scope of economic inquiries by discussing the economic consequences of various ideal social arrangements, and more especially different modes of distributing produce between landlord, capitalist, and labourer Mill certainly redeemed political economy from the reproach of being a dry science Nobody with any interest in human improvement can read his work with indifference And he did this without in any way disturbing the original conception of political economy as the science of cause and effect in the production of wealth One of his most eminent successors, the late Professor Cairnes, thus admirably summed up his work as a political economist —"As he himself used to put it, Ricardo supplied the backbone of the science, but it is not less certain that the limbs, the joints, the muscular developments—all that renders political economy a complete and organized body of knowledge—have been the work of Mill

While his great systematic works were in progress, Mill wrote very little on events or books of the day He turned aside for a few months from his *Political Economy* during the winter of the Irish famine (1846-47) to advocate the creation of peasant-proprietorships as a remedy for distress and disorder in Ireland He found time also to write elaborate articles on French history and Greek history in the *Edinburgh Review* apropos of Michelet, Guizot, and Grote, besides some less elaborate essays

The *Political Economy* was published in 1848 Mill could now feel that the main work he had proposed for himself was accomplished, but, though he wrote comparatively little for some years afterwards, he remained as much as ever on the alert for opportunities of useful influence, and pressed on with hardly diminished enthusiasm in his search for useful truth Among other things, he made a more thorough study of socialist writers, with the result that, though he was not converted to any of their schemes as being immediately practicable, he began to look upon some more equal distribution of the produce of labour as a practicability of the remote future, and to dwell upon the prospect of such changes in human character as might render a stable society possible without the institution of private property This he has called his third stage as a political economist, and he says that he was helped towards it by the lady, Mrs Taylor, who became his wife in 1851, and with whom he had lived in intimate friendship for more than twenty years before It is generally supposed that he writes with a lover's extravagance about this lady's powers when he compares her with Shelley and Carlyle But a little reflexion will show that he wrote with his usual accuracy and sobriety when he described her influence on him He expressly says that he owed none of his technical doctrine to her, that she influenced only his ideals of life for the individual and for society and his language about her is really only a measure of the importance that he attached to such ideals above any systems of reasoned truth There is very little propositional difference between Mill and his father, but it is obvious from what he says that his inner life became very different after he threw off his father's authority This new inner life was strengthened and enlarged by Mrs Taylor We must remember also that Mill in his early years had been so strictly secluded from commonplace sentiment that what the general world would consider commonplace must have come to him with all the freshness of a special revelation

During the seven years of his married life Mill published less than in any other period of his career, but four of his most closely reasoned and characteristic works, the *Liberty*, the *Utilitarianism*, the *Thoughts on Parliamentary Reform*, and the *Subjection of Women*, besides his posthumously published essays on *Nature* and on the *Utility of Religion*, were thought out and partly written in collaboration with his wife. In 1856 he became head of the examiner's office in the India House, and for two years, till the dissolution of the Company in 1858, his official work, never a light task, kept him fully occupied. It fell to him as head of the office to write the defence of the Company's government of India when the transfer of its powers was proposed. Mill was earnestly opposed to the transfer, and the documents in which he substantiated the proud boast for the Company that "few governments even under far more favourable circumstances have attempted so much for the good of their subjects or carried so many of their attempts to a beneficial issue," and exposed the defects of the proposed new government, are models of trenchant and dignified pleading. His prediction that the Indian Secretary's council would serve as a screen and not as a check was in the opinion of many amply verified a few years ago.

On the dissolution of the Company, Mill was offered a seat in the new council, but declined. His retirement from official work was followed almost immediately by his wife's death, and from this calamity he sought relief in active literary occupation. Politics, sociology, and psychology divided as before the energies of his active mind. One of his first cares was to publish with a touching dedication to his wife the treatise on *Liberty* which they had wrought out together, principle by principle and sentence by sentence. This pious duty discharged, he turned to current politics, and published, in view of the impending Reform Bill, a pamphlet on parliamentary reform. The chief feature in this was an idea concerning which he and Mrs Mill often deliberated, the necessity of providing checks against uneducated democracy. His fanciful suggestion of a plurality of votes, proportioned to the elector's degree of education, was avowedly put forward only as an ideal; he admitted that no authentic test of education could for the present be found. An anonymous Conservative caught at the scheme in another pamphlet, proposing income as a test. Soon after, Mill supported in *Fraser's*, still with the same object, Mr Hare's scheme for the representation of minorities. In the autumn of the same year he turned to psychology, reviewing Mr Bain's works in the *Edinburgh Review*.

In this way the indefatigable thinker worked on, throwing himself by turns into the various lines along which he saw prospects of fulfilling his mission as an apostle of progress. In his *Representative Government* (1860) he systematized opinions already put forward in many casual articles and essays. His *Utilitarianism* (published in *Fraser* in 1861) was a closely reasoned systematic attempt to answer objections to his ethical theory and remove misconceptions of it. As the inventor of the term Utilitarianism he was entitled to define its meaning, and he was especially anxious to make it clear that he included in utility the pleasures of the imagination and the gratification of the higher emotions, and to show how powerfully the good of mankind as a motive appealed to the imagination. His treatise on the *Subjection of Women*, in its ruling intention a protest against the abuse of power, was Mill's next work, though it was not published till 1869. His *Examination of Hamilton's Philosophy*, published in 1865, had engaged a large share of his time for three years before. When it first occurred to him that a criticism of the chief of our native intuitional psychologists would cause a wholesome stir and serve enlightenment, he thought only of an article such as he wrote about Austin's *Jurisprudence* or Grote's *Plato*. But he soon found that the subject required a book, and a book appeared which certainly answered the purpose of rousing the sleepy realms of philosophy and theology.

While mainly occupied in those years with philosophical studies, Mill did not remit his interest in current politics. He made his voice heard on the contest in America in 1862, taking the side of the North—then very unpopular in London—and using all his strength to explain what has since been universally recognized as the issue really at stake in the struggle, the abolition of slavery. It was characteristic of the closeness with which he watched current events, and of his zeal in the cause of "lucidity," that when the *Reader*, an organ of science and unpartisan opinion, fell into difficulties in 1865 Mill joined with some distinguished men of science and letters in an effort to keep it afloat. He supplied part of the money for carrying it on, contributed several articles, and assisted the editor, Mr Fraser Rae, with his advice. The effort was vain, though such men as Herbert Spencer, Huxley, Tyndall, Canon Mark Pattison, F. Harrison, Sir Frederick Pollock, and Lockyer were among the contributors.

In 1865 a new channel was opened to his influence. He was requested to stand for Westminster, and agreed on conditions strictly in accordance with his principles of parliamentary election. He would not canvass, nor pay agents to canvass for him, nor would he engage to attend to the local business of the constituency. He was with difficulty persuaded even to address a meeting of the electors. The story of this remarkable election has been told by Mr James Beal, one of the most active supporters of Mill's candidature. In parliament he adhered to his lifelong principle of doing only work that needed to be done and that nobody else seemed equally able or willing to do. It may have been a consciousness of this fact which prompted a remark made by the Speaker that Mill's presence in parliament elevated the tone of debate. The impression made by him in parliament is in some danger of being forgotten because he was not instrumental in carrying any great measure that might serve as an abiding memorial. But although in one of his first speeches against the suspension of the Habeas Corpus Act in Ireland he was very unfavourably received, Mill thoroughly succeeded in what is called "gaining the ear of the House." The only speech made by him during his three years in parliament that was listened to with impatience was, curiously enough, his speech in favour of counteracting democracy by providing for the representation of minorities. His attack on the conduct of General Eyre in Jamaica was listened to, but with repugnance by the majority, although his action in this matter in and out of parliament was far from being ineffectual. He took an active part in the debates on Mr Disraeli's Reform Bill and helped to extort from the Government several useful modifications of the Bill for the Prevention of Corrupt Practices. The reform of land tenure in Ireland, the representation of women, the reduction of the national debt, the reform of London government, the abrogation of the declaration of Paris were among the topics on which he spoke with marked effect. He took occasion more than once to enforce what he had often advocated in writing, England's duty to intervene in Continental politics in support of the cause of freedom. As a speaker Mill was somewhat hesitating, pausing occasionally as if to recover the thread of his argument, but he showed great readiness in extemporaneous debate. Viewed as a candidate for ministerial office, he might be regarded as a failure in parliament, but there can be no doubt that his career there greatly extended his influence.

Mill's subscription to the election expenses of Mr Bradlaugh, and his attitude towards Governor Eyre, are generally regarded as the main causes of his defeat in the general election of 1868 But, as he suggests himself, his studied advocacy of unfamiliar projects of reform had made him unpopular with moderate Liberals When he was first elected on a sudden impulse of enthusiasm, extremely little was known about him by the bulk of the electorate, and his writing about checks against democracy had prepared many for a more conservative attitude on questions of practical politics He retired with a sense of relief to his cottage and his literary life at Avignon His parliamentary duties and the quantity of correspondence brought upon him by increased publicity had absorbed nearly the whole of his time The scanty leisure of his first recess had been devoted to writing his St Andrews rectorial address on higher education and to answering attacks on his criticism of Hamilton, of the second, to annotating, in conjunction with Mr Bain and Mr Findlater, his father s *Analysis of the Mind* But now he could look forward to a literary life pure and simple, and his letters show how much he enjoyed the change His little cottage was filled with books and newspapers, the beautiful country round it furnished him with a variety of walks, he read, wrote, discussed, walked, botanized His step-daughter, Miss Taylor, his constant companion after his wife s death, "architect and master mason all in one, carried out various improvements in their quiet home for the philosopher s comfort Helen, he wrote to Mr Thornton, "has carried out her long cherished scheme (about which she tells me she consulted you) of a 'vibratory for me, and has made a pleasant covered walk, some 30 feet long, where I can vibrate in cold or rainy weather The terrace, you must know as it goes round two sides of the house, has got itself dubbed the semi circumgyratory In addition to this Helen has built me a herbarium, a little room fitted up with closets for my plants shelves for my botanical books, and a great table whereon to manipulate them all Thus you see with my herbarium, my vibratory and my semi circumgyratory I am in clover, and you may imagine with what scorn I think of the House of Commons, which, comfortable club as it is said to be could offer me none of these comfort or, more perfectly speaking these necessaries of life Mill was an enthusiastic botanist all his life long and a frequent contributor of notes and short papers to the *Phytologist* One of the things that he looked forward to during his last journey to Avignon was seeing the spring flowers and completing a flora of the locality His delight in scenery frequently appears in letters written to his friends during his summer and autumn tours

No recluse ever had a more soothing retreat than Mill s Avignon cottage but to the last he did not relax his laborious habits nor his ardent outlook on human affairs The essays in the fourth volume of his *Dissertations*—on endowments on land, on labour, on metaphysical and psychological questions—were written for the *Fortnightly Review* at intervals after his short parliamentary career One of his first tasks was to send his treatise on the *Subjection of Women* through the press The essay on *Theism* was written soon after The last public work in which he engaged was the starting of the Land Tenure Reform Association The interception by the state of the unearned increment, and the promotion of co operative agriculture were the most striking features in his programme He wrote in the *Examiner* and made a public speech in favour of the association a few months before his death The secret of the ardour with which he took up this question probably was his conviction that a great struggle was impending in Europe between labour and capital He regarded his project as a timely compromise

Mill died at Avignon on the 8th of May 1873

Within the limits of this article it is impossible to attempt a criticism of Mill s conclusions in so many fields of research, one must be content with trying to indicate the purpose and the spirit of his work Perhaps we still stand too near to judge without bias some years hence men will be better able to say whether he made sciolism less reckless or brought mankind appreciably nearer that dominion of the wisest which was the remote goal of his endeavour It will be long before humanity finds a nobler example of the searcher after the best means of social improvement He sought after clear ideas with the ardour of a mystic, the patience and laborious industry of a man of science he encountered opponents with a generosity and a courtesy worthy of any *preux chevalier* of mediæval romance while he was not inferior to that ideal in the vigour of his blows against injustice As regards his influence it has been well said that no calculus can integrate the innumerable pulses of knowledge and of thought that he has made to vibrate in the minds of his generation He quickened thought upon every problem that he touched Any estimate of Mill s service to political or philosophical thought at this moment is liable to be injuriously affected by the temporary discredit into which some of his doctrines have fallen He was not infallible he made no claim to dogmatic authority But in criticism of detail according to our present light we may easily blind ourselves to the greatness of the work that Mill accomplished in the development of opinion (W M)

MILLAU, or MILHAU, capital of an arrondissement in the department of Aveyron, France, is situated on the left bank of the Tarn, half a mile below the point at which that river is joined by the Dourbie, and 48 miles to the south east of Rodez, on the Rodez and Montpellier line Itself 1210 feet above the level of the sea, it is overlooked by hills covered with vineyards and fruit trees or by bare and scarped rocks The streets of Millau are narrow, and some of the houses of great antiquity, but the town is surrounded by spacious boulevards On two sides the Place d Armes is adorned by stone columns supporting galleries of wood, the only buildings of special interest are the Romanesque church of Notre Dame, and the belfry of the old hotel de ville The principal industry is the manufacture of gloves, but various branches of the leather manufacture are also carried on The chief articles of commerce are wool (both raw and prepared), Roquefort cheese, wine, almonds, and live stock The population in 1881 was 16,628

The viscounts of Millau are mentioned as early as the 10th century in the 16th it became one of the leading strongholds of the Reformed party in the south of France Its industry suffered severely by the revocation of the edict of Nantes

MILLENNIUM In the history of Christianity three main forces are found to have acted as auxiliaries of the gospel They have elicited the ardent enthusiasm of many whom the bare preaching of the gospel would never have made decided converts These are (1) a belief in the speedy return of Christ and in His glorious reign on earth, (2) mystical contemplation which regards heavenly blessings as a possible possession in the present life and (3) faith in a divine predestination of some to salvation and others to perdition Each of these forces has at particular times proved too strong for church authority and burst the embankments with which the church had at once narrowed and protected Christian life and thought They have produced ecclesiastical, social, and political convulsions, where the elemental force of religious conviction has destroyed all organization, whether of church or of state They have released from its fetters the free spirit of Christianity, though often enough they have associated with it a fanaticism more damaging to the gospel than the temporizing policy of the hierarchy

First in point of time came the faith in the nearness of Christ s second advent and the establishing of His reign of glory on the earth Indeed it appears so early that it might be questioned whether it ought not to be regarded as an essential part of the Christian religion That question, however, will scarcely be answered in the affirmative The ideas of the Sermon on the Mount, or the pregnant thoughts of the Pauline theology, are independent of the expectation that the kingdom of glory will shortly be established On the other hand, it must be admitted that this expectation was a prominent feature in the earliest proclamation of the gospel, and materially contributed to its success If the primitive churches had been under the necessity of framing a "Confession of Faith, it would certainly have embraced those pictures by means of which the near future was distinctly realized But then these pictures and dreams and hopes were just the things that made systematized doctrine impossible, it is possible to formulate the mythological ideas, but not the shifting imagery of the imagination

In the anticipations of the future prevalent amongst the early Christians (*c* 50–150) it is necessary to distinguish a fixed and a fluctuating element The former includes (1) the notion that a last terrible battle with the enemies of God was impending (2) the faith in the speedy return of Christ (3) the conviction that Christ will judge all men, and (4) will set up a kingdom of glory on earth To the latter belong views of the Antichrist of the heathen world power, of the place, extent and duration of the earthly kingdom of Christ, &c These remained in a state of solution, they were modified from day to day, partly because of the changing circumstances of the present by which forecasts of the future were regulated, partly because the indications—real or supposed—of the ancient prophets always admitted of new combinations and constructions But even here certain positions were agreed on in large sections of Christendom Amongst these was the expectation that the future kingdom of Christ on earth should have a fixed duration,—according to the most prevalent opinion, a duration of one thousand years From this fact the whole ancient Christian eschatology was known in later times as ' chiliasm, —a name which is not strictly accurate, since the doctrine of the millennium was only one feature in its scheme of the future

1 This idea that the Messianic kingdom of the future on earth should have a definite duration has—like the whole eschatology of the primitive church—its roots in the Jewish apocalyptic literature where it appears at a comparatively late period At first it was assumed that the Messianic kingdom in Palestine would last for ever (so the prophets *cf* Jerem xxiv 6 Ezek xxxvii 25 Joel iv 20 Daniel vi 27 Sibyll iii 49 *sq* 766 Psalt Salom xvii 4 Enoch lxii 14), and this seem always to have been the most widely accepted view (John xii 34) But from a comparison of prophetic passages of the Old Testament learned apocalyptic writers came to the conclusion that a distinction must be drawn between the earthly appearance of the Messiah and the appearance of God Himself amongst His people and in the Gentile world for the final judgment As a necessary consequence a limited period had to be assigned to the Messianic kingdom It is not altogether improbable that the mysterious references to the sufferings of the Messiah had also an influence on some minds This, however, is doubtful It is certain at all events that the whole conception marks the beginning of the dissolution of realistic and sensuous views of the future The age was too advanced to regard the earthly Messianic kingdom as the end There was an effort to find a place among the hopes of the future for those more spiritual and universal anticipations, according to which eternal and heavenly blessedness will be the portion of the faithful, this earth and heaven will pass away, and God will be all in all As to the period to be assigned to this earthly kingdom, no agreement was ever reached in Judaism, any more than in the detailed descriptions of its joys and pleasures According to the Apocalypse of Baruch (xl 3) this kingdom will last "donec finiatur mundus corruptionis ' In the Book of Enoch (xci 12) "a week is specified, in the Apocalypse of Ezra (vii 28 *sq*) four hundred years This figure, corresponding to the four hundred years of Egyptian bondage, occurs also in the Talmud (Sanhedrin 99*a*) But this is the only passage, the Talmud has no fixed doctrine on the point The view most frequently expressed there (see Von Otto in *Hilgenfeld s Zeitschrift*, 1877, p 527 *sq*) is that the Messianic kingdom will last for one thousand (some said two thousand) years "In six days God created the world, on the seventh He rested But a day of God is equal to a thousand years (Ps xc 4) Hence the world will last for six thousand years of toil and labour, then will come one thousand years of Sabbath rest for the people of God in the kingdom of the Messiah This idea must have already been very common in the first century before Christ The combination of Gen i, Dan ix, and Ps xc 4 was peculiarly fascinating

2 Jesus Himself speaks of only one return of the Son of Man—His return to judgment In speaking of it and of the glorious kingdom He is to introduce, He makes use of apocalyptic images (Matt viii 11, xxvi 29 Luke xxii 16 Matt xix 28), but nowhere in the discourses of Jesus is there a hint of a limited duration of the Messianic kingdom The apostolic epistles are equally free from any trace of chiliasm (neither 1 Cor xv 23 *sq* nor 1 Thess iv 16 *sq* points in this direction) In the Apocalypse of John however, it occurs in the following shape (chap xx) After Christ has appeared from heaven in the guise of a warrior, and vanquished the antichristian world power the wisdom of the world, and the devil, those who have remained steadfast in the time of the last catastrophe and have given up their lives for their faith shall be raised up, and shall reign with Christ on this earth as a royal priesthood for one thousand years At the end of this time Satan is to be let loose again for a short season, he will prepare a new onslaught but God will miraculously destroy him and his hosts Then will follow the general resurrection of the dead, the last judgment and the creation of new heavens and a new earth That *all* believers will have a share in the first resurrection and in the Messianic kingdom is an idea of which John knows nothing The earthly kingdom of Christ is reserved for those who have endured the most terrible tribulation who have withstood the supreme effort of the world power,—that is, for those who are actually members of the church of the last days The Jewish expectation is thus considerably curtailed in the hands of John as it is also shorn of its sensual attractions ' Blessed and holy is he that hath part in the first resurrection, on such the second death hath no power but they shall be priests of God and of Christ and shall reign with Him a thousand years More than this John does not say But other ancient Christian authors were not so cautious Accepting the Jewish apocalypses as sacred books of venerable antiquity they read them eagerly, and transferred their contents bodily to Christianity Nay more, the Gentile Christians took possession of them and just in proportion as they were neglected by the Jews—who after the war of Bar Cochba, became indifferent to the Messianic hope and hardened themselves once more in devotion to the law—they were naturalized in the Christian communities The result was that these books became "Christian documents it is entirely to Christian and not to Jewish, tradition that we owe their preservation The Jewish expectations are adopted, for example by Papias, by the writer of the epistle of Barnabas and by Justin Papias actually confounds expressions of Jesus with verses from the Apocalypse of Baruch referring to the amazing fertility of the days of the Messianic kingdom (Papias in Iren v 33) Barnabas (*Ep*, 15) gives us the Jewish theory (from Gen i and Ps xc 4) that the present condition of the world is to last six thousand years

from the creation, that at the beginning of the Sabbath (the seventh millennium) the Son of God appears, to put an end to the time of the unjust one, to judge the ungodly and renew the earth But he does not indulge, like Papias, in sensuous descriptions of this seventh millennium, to Barnabas it is a time of rest of sinlessness, and of a holy peace It is not the end however it is followed by an eighth day of eternal duration — the beginning of another world So that in the view of Barnabas the Messianic reign still belongs to οὗτος ὁ αιων Justin (*Dial*, 80) speaks of chiliasm as a necessary part of complete orthodoxy, although he knows Christians who do not accept it He believes with the Jews, in a restoration and extension of the city of Jerusalem he assumes that this city will be the seat of the Messianic kingdom, and he takes it as a matter of course that there all believers (here he is at one with Trypho) along with patriarchs and prophets will enjoy perfect felicity for one thousand years In fact he reads this view into the Apocalypse of John, which he understands to mean that before the general resurrection all believers are to rule for a time with Christ on earth That a philosopher like Justin with a bias towards an Hellenic construction of the Christian religion should nevertheless have accepted its chiliastic elements is the strongest proof that these enthusiastic expectations were inseparably bound up with the Christian faith down to the middle of the 2d century And another proof is found in the fact that even a speculative Jewish Christian like Cerinthus not only did not renounce the chiliastic hope, but pictured the future kingdom of Christ as a kingdom of sensual pleasures of eating and drinking and marriage festivities (Euseb *H E*, iii 28, vii 25)

3 After the middle of the 2d century these expectations were gradually thrust into the background They would never have died out, however had not circumstances altered and a new mental attitude been taken up The spirit of philosophical and theological speculation and of ethical reflexion which began to spread through the churches did not know what to make of the old hopes of the future To a new generation they seemed paltry, earthly, and fantastic and far seeing men had good reason to regard them as a source of political danger But more than this these wild dreams about the glorious kingdom of Christ began to disturb the organization which the churches had seen fit to introduce In the interests of self preservation against the world, the state and the heretics the Christian communities had formed themselves into compact societies with a definite creed and constitution, and they felt that their existence was threatened by the white heat of religious subjectivity So early as the year 170, a church party in Asia Minor the so called Alogi—rejected the whole body of apocalyptic writings and denounced the Apocalypse of John as a book of fables All the more powerful was the reaction In the so-called Montanistic controversy (160 220) one of the principal issues involved was the continuance of the chiliastic expectations in the churches The Montanists of Asia Minor defended them in their integrity, with one slight modification they announced that Pepuza, the city of Montanus would be the site of the New Jerusalem and the millennial kingdom Modifications of this kind, which have often appeared in later times in connexion with the revival of millenarianism, are a striking evidence of the tendency of every sect to regard its own little membership as the centre of the world and its fortunes as the kernel of universal history After the Montanistic controversy, chiliastic views were more and more discredited in the Greek Church, they were, in fact, stigmatized as "Jewish" and consequently "heretical" It was the Alexandrian theology that superseded them, that is to say, Neo Platonic mysticism triumphed over the early Christian hope of the future, first among the "cultured," and then, when the theology of the "cultured" had taken the faith of the "uncultured" under its protection, amongst the latter also About the year 260 an Egyptian bishop, Nepos, in a treatise called ἔλεγχος ἀλληγοριστῶν, endeavoured to overthrow the Origenistic theology and vindicate chiliasm by exegetical methods Several congregations took his part but ultimately Dionysius, bishop of Alexandria, succeeded in healing the schism and asserting the allegorical interpretation of the prophets as the only legitimate exegesis During this controversy Dionysius became convinced that the victory of mystical theology over "Jewish" chiliasm would never be secure so long as the Apocalypse of John passed for an apostolic writing and kept its place among the homologoumena of the canon He accordingly raised the question of the apostolic origin of the Apocalypse and by reviving old difficulties, with ingenious arguments of his own, he carried his point At the time of Eusebius the Greek Church was saturated with prejudice against the book and with doubts as to its canonicity In the course of the 4th century it was removed from the Greek canon, and thus the troublesome foundation on which chiliasm might have continued to build was got rid of The attempts of Methodius of Tyre at the beginning of the 4th century and Apollinarius of Laodicea about 360 to defend chiliasm and assail the theology of Origen had no result For many centuries the Greek Church kept the Johannine Apocalypse out of its canon, and consequently chiliasm remained in its grave It was considered a sufficient safeguard against the spiritualizing eschatology of Origen and his school to have rescued the main doctrines of the creed and the *regula fidei* (the visible advent of Christ, eternal misery and hell fire for the wicked) Anything beyond this was held to be Jewish It was only the chronologists and historians of the church who, following Julius Africanus made use of apocalyptic numbers in their calculations, while court theologians like Eusebius entertained the imperial table with discussions as to whether the dining hall of the emperor—the second David and Solomon the beloved of God—might not be the New Jerusalem of John's Apocalypse Eusebius was not the first who dabbled in such speculations Dionysius of Alexandria had already referred a Messianic prediction of the Old Testament to the emperor Gallienus But mysticism and political servility between them gave the death blow to chiliasm in the Greek Church It never again obtained a footing there, for, although, late in the Middle Ages, the Book of Revelation—by what means we cannot tell—did recover its authority, the church was by that time so hopelessly trammelled by a magical cultus as to be incapable of fresh developments In the Semitic churches of the East (the Syrian, Arabian, and Æthiopian), and in that of Armenia, the apocalyptic literature was preserved much longer than in the Greek Church They were very conservative of ancient traditions in general, and hence chiliasm survived amongst them to a later date than in Alexandria or Constantinople It is to these churches that we are mainly indebted for the extensive remains of the old apocalyptic literature which we now possess From remote cloisters of the East Europe has recovered within the last forty years many works of this kind which once enjoyed the highest repute throughout Christendom

4 But the Western Church was also more conservative than the Greek Her theologians had, to begin with, little turn for mystical speculation, their tendency was rather to reduce the gospel to a system of morals Now for the moralists chiliasm had a special significance as the one distinguishing feature of the gospel, and the only thing

that gave a specifically Christian character to their system. This, however, holds good of the Western theologians only after the middle of the 3d century. The earlier fathers, Irenæus, Hippolytus, Tertullian, believed in chiliasm simply because it was a part of the tradition of the church and because Marcion and the Gnostics would have nothing to do with it. Irenæus (v. 28, 29) has the same conception of the millennial kingdom as Barnabas and Papias, and appeals in support of it to the testimony of disciples of the apostles. Hippolytus, although an opponent of Montanism, was nevertheless a thorough-going millennarian (see his book *De Antichristo*). Tertullian (cf. especially *Adv. Marcion*, 3) aimed at a more spiritual conception of the millennial blessings than Papias had, but he still adhered, especially in his Montanistic period, to all the ancient anticipations. It is the same all through the 3d and 4th centuries with those Latin theologians who escaped the influence of Greek speculation. Commodian, Victorinus Pettavensis, Lactantius, and Sulpicius Severus were all pronounced millennarians, holding by the very details of the primitive Christian expectations. They still believe, as John did, in the return of Nero as the Antichrist; they still expect that after the first resurrection Christ will reign with His saints "in the flesh" for a thousand years. Once but only once (in the Gospel of Nicodemus) the time is reduced to five hundred years. Victorinus wrote a commentary on the Apocalypse of John; and all these theologians, especially Lactantius, were diligent students of the ancient Sibylline oracles of Jewish and Christian origin, and treated them as divine revelation. As to the canonicity and apostolic authorship of the Johannine Apocalypse no doubts were ever entertained in the West; indeed an Apocalypse of Peter was still retained in the canon in the 3d century. That of Ezra, in its Latin translation, must have been all but a canonical book,—the numbers of extant manuscripts of the so-called 4 Ezra being incredibly great, while several of them are found in copies of the Latin Bible at the beginning of the 16th century. The Apocalypse of Hermas was much read till far through the Middle Ages, and has also kept its place in some Bibles. The apocalyptic "Testamenta duodecim Patriarcharum" was a favourite reading-book; and Latin versions of ancient apocalypses are being continually brought to light from Western libraries (e.g., the *Assumptio Mosis*, the *Ascensio Jesaiæ*, &c.). All these facts show how vigorously the early hopes of the future maintained themselves in the West. In the hands of moralistic theologians, like Lactantius, they certainly assume a somewhat grotesque form, but the fact that these men clung to them is the clearest evidence that in the West millennarianism was still a point of "orthodoxy" in the 4th century.

This state of matters, however, gradually disappeared after the end of the 4th century. The change was brought about by two causes,—first, Greek theology, which reached the West chiefly through Jerome, Rufinus, and Ambrose, and, second, the new idea of the church wrought out by Augustine on the basis of the altered political situation of the church. Jerome, the pupil of the Greeks, feels himself already emancipated from "opiniones Judaicæ"; he ridicules the old anticipations; and though he does not venture to reject them, he and the other disciples of the Greeks did a great deal to rob them of their vitality. At the same time the influence of Greek theology was by no means so great in the West that this of itself could have suppressed chiliastic views. It was reserved for Augustine to give a direction to Western theology which carried it clear of millennarianism. He himself had at one time believed in it; he too had looked forward to the holy Sabbath which was to be celebrated by Christ and His people on earth. But the signs of the times pointed to a different prospect. Without any miraculous interposition of God, not only was Christianity victorious on earth, but the church had attained a position of supremacy. The old Roman empire was tottering to its fall; the church stood fast, ready to step into its inheritance. It was not simply that the world-power, the enemy of Christ, had been vanquished; the fact was that it had gradually abdicated its political functions in favour of the church. Under these circumstances Augustine was led, in his controversy with the Donatists and as an apologist, to idealize the political side of the catholic church,—to grasp and elaborate the idea that the church is the kingdom of Christ and the city of God. Others before him may have taken the same view, and he on the other hand never forgot that true blessedness belongs to the future; but still he was the first who ventured to teach that the catholic church, in its empirical form, was the kingdom of Christ, that the millennial kingdom had commenced with the appearing of Christ, and was therefore an accomplished fact. By this doctrine of Augustine's, the old millennarianism, though not completely extirpated, was at least banished from the realm of dogmatics. For the official theology of the church it very soon became a thing of the past; certain elements of it were even branded as heretical. It still lived on, however, in the lower strata of Christian society, and in certain undercurrents of tradition it was transmitted from century to century. At various periods in the history of the Middle Ages we encounter sudden outbreaks of millennarianism, sometimes as the tenet of a small sect, sometimes as a far-reaching movement. And since it had been suppressed, not, as in the East, by mystical speculation, its mightiest antagonist, but by the political church of the hierarchy, we find that wherever chiliasm appears in the Middle Ages it makes common cause with all enemies of the secularized church. It strengthened the hands of church democracy; it formed an alliance with the pure souls who held up to the church the ideal of apostolic poverty; it united itself for a time even with mysticism in a common opposition to the supremacy of the church; now it lent the strength of its convictions to the support of states and princes in their efforts to break the political power of the church. It is sufficient to recall the well-known names of Joachim of Floris, of all the numerous Franciscan spiritualists, of the leading sectaries from the 13th to the 15th century who assailed the papacy and the secularism of the church, above all, the name of Occam. In these men the millennarianism of the ancient church came to life again; and in the revolutionary movements of the 15th and 16th centuries,—especially in the Anabaptist movement,—it appears with all its old uncompromising energy. If the church and not the state was regarded as Babylon, and the pope declared to be the Antichrist, these were legitimate inferences from the ancient traditions and the actual position of the church. But of course the new chiliasm was not in every respect identical with the old. It could not hold its ground without admitting certain innovations. The "everlasting gospel" of Joachim of Floris was a different thing from the announcement of Christ's glorious return in the clouds of heaven; the "age of the spirit" which mystics and spiritualists expected contained traits which must be characterized as "modern"; and the kingdom of the Anabaptists in Munster was a Satanic caricature of that kingdom in which the Christians of the 2d century looked for a peaceful Sabbath rest. Only we must not form our ideas of the great apocalyptic and chiliastic movement of the first decades of the 16th century from the rabble in Munster. There were pure evangelical forces at work in it, and many Anabaptists need not shun comparison with the Christians of the apostolic and post-apostolic ages.

The German and Swiss Reformers also believed that the end of the world was near, but they had different aims in view from those of the Anabaptists It was not from poverty and apocalypticism that they hoped for a reformation of the church In contrast to the fanatics, after a brief hesitation they threw millennarianism overboard, and along with it all other "opiniones Judaicæ" They took up the same ground in this respect which the Roman Catholic Church had occupied since the time of Augustine How millennarianism nevertheless found its way, with the help of apocalyptic mysticism and Anabaptist influences, into the churches of the Reformation, chiefly among the Reformed sects, but afterwards also in the Lutheran Church, how it became incorporated with Pietism, how in recent times an exceedingly mild type of "academic chiliasm has been developed from a belief in the verbal inspiration of the Bible, how finally new sects are still springing up here and there with apocalyptic and chiliastic expectations,—these are matters which cannot be fully entered upon here But one remark ought to be made in conclusion A genuine and living revival of chiliastic hopes is always a sign that the church at large has become secularized to such a degree that tender consciences can no longer feel sure of their faith within her In this sense all chiliastic phenomena in the history of the church demand respectful attention But when attempts are made to find room for millennarianism in a dogmatic system, it must always assume a form in which it would be utterly unrecognizable to the millennarians of the ancient church, who, just because they were millennarians, despised dogmatic, in the sense of philosophical theology The claims of chiliasm are sufficiently met by the acknowledgment that in former times it was associated—to all appearance inseparably associated—with the gospel itself Those who try to remodel it, so as to conserve its "elements of truth, put contempt on it while they destroy it for it was in its day the most uncompromising enemy of all remodelling, and it can only exist along with the unsophisticated faith of the early Christians

Cf Schürer, *Lehrbuch der Neutestamentlichen Zeitgeschichte* 1874, §§ 28, 29 Corrodi, *Kritische Geschichte des Chiliasmus*, 1781 A thorough history of chiliasm has not yet appeared (A HA)

MILLER, HUGH (1802–1856), eminent in science and literature, and one of the most remarkable among self taught men of genius, was born at Cromarty, on the north east coast of Scotland, on the 10th of October 1802 His father, a sagacious and strong willed seaman, who earned a livelihood by sailing his own sloop, perished at sea when Hugh was five years old His mother looked much, in the upbringing of her son, to her two brothers, James and Alexander Wright, the one a saddler, the other a carpenter Scrupulous integrity, sincere religion, unflagging industry, and resolute contentment were the lessons which these men, not so much by precept as by example, impressed upon the boy But young Miller had inherited from his father a strong individuality and obstinate force of will, and began at a very early age to take a line of his own The enchantment of open air and freedom—the irresistible charm of mother nature on the hill and by the sea—made him at thirteen an incorrigible truant, and his schoolmaster thought it likely that he would prove a dunce Nevertheless the truant schoolboy was already giving indications of the destination of the man At an age too early to date he had found in his pen a divining rod that led him to waters of inexhaustible delight His mother summed up, in the singular dialect of the district, the impression derived from her son's boyhood and youth in the words, "he was aye vritin." But the writing from the first, and increasingly as time went on, could be discriminated from the ordinary productions of boyhood A continuity of idea, an indefinable grace and freshness, marked his performances. They were never bombastic or verbose At no period of his life did he suffer from a flux of words But, boy and man, he had a felicitous knack of fitting words into their right places and avoiding jerkiness and inequality In verse he lacked the passionate intensity required for true rhythmic movement, but he had a fine sense of cadence and modulation in prose

It is a curious fact that what determined Hugh Miller to apprentice himself to a stone mason was his delight in literary composition Unemployed during the winter frosts, the mason, he perceived, could enjoy for some months every year the ecstacy of writing One result of his decision was that he never learned any language but English Another was that fifteen years of the quarry and the hewing shed, with stern experiences of over work and privation, sowed in his frame the seeds of incurable disease Meanwhile the advantages of his decision were indisputable Under the discipline of labour the refractory schoolboy became a thoughtful, sober minded man Miller always looked back to his years of hand labour with a satisfaction that has something in it of solemnity and pathos "Noble, upright, self relying toil,' he exclaims, "who that knows thy solid worth and value would be ashamed of thy hard hands, and thy soiled vestments, and thy obscure tasks,—thy humble cottage, and hard couch, and homely fare!"

It cannot be added that his fifteen years of close and constant intercourse with fellow workmen inspired him with much respect for their class He was most unfortunate in his comrades during the two seasons, 1824 and 1825, when he worked at Niddrie in the neighbourhood of Edinburgh Swinish in their enjoyments, meanly selfish in their class ambitions, and fatuously subject to talking charlatans, that Niddrie squad of reprobates which he describes in *My Schools and Schoolmasters* stamped on the mind of Hugh Miller an indelible conviction of the incapacity and degradation of the hand workers

Returning to Cromarty, he worked in happy patience as a stone-cutter year after year, sedulously prosecuting at the same time the grand object of his ambition, to write good English He found time to invigorate and enrich his mind by careful reading, and was habitually and keenly observant both of man and of nature His reading was not extensive but well chosen, and embraced Locke and Hume, Goldsmith and Addison were, more than any others, his masters in style It was to get time to write that he had become a stone mason, another of the surprises of his career is that it was in advertising himself as a mason that he came before the world as a literary man A stonemason, figuring as a poetical contributor to the *Inverness Courier*, might, he thought, be asked by some of the readers to engrave inscriptions on tombs He therefore forwarded some of his verses to the editor These seem to have been consigned to the waste paper basket, which had been the fate of an "Ode on Greece" offered to the *Scotsman* when he was at Edinburgh Piqued by his second failure, he now resolved, at all hazards, to see himself in print In 1829 appeared the small volume containing *Poems Written in the Leisure Hours of a Journeyman Mason* It procured its author the valuable friendship of Mr Robert Carruthers, and was favourably noticed by the press Miller looked at his poems in print, and concluded, at once and irreversibly, that he would not succeed as a poet It was a characteristic and very manly decision, proving that there was no fretting vanity in his disposition. Doubtless also it was right His field was prose But, though his poems yielded nothing in the way of fortune, they were a beginning of fame The simple natives of Cromarty began to think him a wonder Some very eloquent letters on the herring fishery extended his reputation Good judges in Edinburgh detected in his work the mint mark of genius, and Miller's first prose volume, *Scenes and Legends of Cromarty*, was published there in 1835 In the interval he had become the accepted lover of Miss Lydia Fraser, a young lady of great personal attractions, rare intellectual gifts, and glowing sympathy with all that was good and brave and bright Her affection naturally steadied him in his resolution to emerge from the hand-working class, the mallet and chisel gradually dropped from his grasp, and when his prose venture appeared he was being initiated, in Linlithgow, into the duties of a bank clerk On his return to Cromarty he found employment in the local branch of the Commercial Bank

He was a married man, and his tent seemed stably fixed at Cromarty, when the agitation that preceded the Disruption of 1843 made the air of Scotland vibrate Miller loved his church, and deliberately esteemed her the most valuable institution possessed by the Scottish people Fervently as he had sympathized with those who procured political representation for Scotland by the Reform Bill, he still more fervently took part with those who claimed that Scottish congregations should have no pastors thrust upon them In the summer of 1839 he wrote his famous pamphlet letter to Lord Brougham, Dr Candlish read it with "nothing short of rapture , and the first days of 1840 saw Miller installed in the editorial chair of the *Witness* newspaper, published twice a week in Edinburgh to advocate the cause of non intrusion and spiritual independence He continued to edit the *Witness* till his death, which took place in the night between the 23d and 24th of December 1856 Unremitting brain work had overtaxed a system permanently injured by the hardships of his early mason life, reason at length gave way, and Miller died by a pistol shot fired by his own hand A *post mortem* examination, attested by four medical men of the highest character, evinced the presence of "diseased appearances ' in the brain, and he left a few words indicating the form taken by the insane delusion which had mastered him

During the three years preceding the Disruption, championship of the church by Miller did more, probably, than any other single agency to win for it the suffrage of the Scottish people Months before the day of separation, the name "Free Church was prospectively assigned to the party proposing to sever connexion with the state and, whether Hugh Miller suggested the name or did not, he was one of the chief architects of the institution Nor has the sequel shown that his labour was vain

But long ere now an enthusiasm parallel in intensity with that which he felt for his country and his church, and to which even his old literary enthusiasm had become subservient, had taken possession of him From infancy he had been a keenly interested observer of all natural facts and objects, and during his career as apprentice and journeyman mason he had accumulated a vast store of the particular information belonging to the geologist But it was not until later that he expressly undertook the study of geology We still find him, when twenty seven, laying down charts of study and production without a word about science When, however, he had convinced himself that his road to the stars was not by poetry, and when the limited success of his prose tales and literary essays in the volume on Cromarty suggested a profound misgiving as to the adequacy of his purely literary materials to produce an important result, he bethought him of his hoard of scientific knowledge, and addressed himself with the concentrated energy of mature manhood to geological reading and geological researches. These, in fact, were not new to him, and he was much impressed by the interest excited among scientific readers by a geological chapter in the *Scenes and Legends* His chief master was Lyell, whom he reverenced henceforward as one of the greatest of living men The principal scene of his own investigations was the Cromarty district, where he ransacked every wrinkle of the hill side, and traced every stratum sawn through by the watercourse, and where, on the beach at ebb, in indurated clay of bluish tint and great tenacity, belonging to the Old Red Sandstone formation, he discovered and dug out nodules which, when laid open by a skilful blow of the hammer, displayed certain organisms that had never been seen by a human eye He had entered upon correspondence with Murchison and Agassiz, and "fellows of the Geological Society and professors of colleges had been brought by his descriptions "to explore the rocks of Cromarty Along with the patriotic and religious enthusiasm, therefore, that burned within him when he went to champion his church in Edinburgh, there glowed, in the depths of his heart, not indeed a stronger but a more gentle and perhaps a dearer enthusiasm for that science in which, he felt persuaded, he had something of his own to say, something to which the world of culture would be glad to listen So early as September 1840 there began to appear in the *Witness* a series of articles entitled "The Old Red Sandstone They attracted immediate and eager attention, and the month was not at an end when, at the meeting of the British Association, Murchison brought them under the notice of the geological section, presided over by Lyell. Agassiz, already familiar from Miller's correspondence with the organisms described, contributed information respecting them, and proposed that one of the most remarkable of the fossils should be called *Pterichthys Milleri* Buckland joined warmly in the encomiums of Murchison and Agassiz, vowing that "he would give his left hand to possess such powers of description as this man ' The articles which met with so enthusiastic a reception from the most eminent geologists in Europe formed the nucleus of a book soon after published, and entitled *The Old Red Sandstone* It established Miller's reputation not only as an original geologist but as a practical thinker of great sagacity, and as a lucid and fascinating writer He had at last fairly found his hand, it is impossible to turn from the *Scenes and Legends* to the new volume without feeling that the spirit of the author has become more exultant, his touch at once stronger and more free

During his seventeen years of residence in Edinburgh he published a variety of books all of them more or less geological but claiming attention not on account of their geology alone His *First Impressions of England and its People* the fruit of eight weeks wandering arranged in the leisure hours of a hard worked editor will be best appreciated when we contrast its grace and gentleness the classic moderation of its tone the quiet vivacity and freshness of its observation the sense and sentiment and justice of its criticism, with the smartness of the ordinary newspaper correspondent or the vulgarity and the impudent omniscience of the conventional book of travels Apart from its masterly descriptions partly geological partly scenic and that prose poem on the ubiquity of the ocean which, though brief, will compare not unfavourably with select pages from Wilson or from Ruskin its two passages on Westminster Abbey and Stratford on Avon would alone suffice to prove that the Cromarty stone mason was a man of extraordinary genius Of his autobiographical volume, *My Schools and Schoolmasters*, no opinion but one has ever been expressed It ranks among the finest masterpieces of its kind in the English language

As a geologist his reputation is securely based upon his actual discovery of important fossil organisms one of which bears his name, and on his contributions, thoroughly serviceable at the time they were made, to our knowledge of the formation in which those organisms occur His eye to eye acquaintance with nature is attested on every page and if his enthusiasm does not often rise into spray and surge of rapture, it is a deep ground swell perceptible in all he wrote His powers of observation were singularly strong and accurate, and were accompanied with the most careful reflexion and a fine rich glow of imaginative vision His discernment of the true position of the ventral plate of *Pterichthys*, when the best ichthyologists unanimously insisted on its being dorsal, affords one of the nicest illustrations to be found of an observational faculty which reasons as well as sees.

He was also, in his principal geological books *The Footsteps of the Creator* and *The Testimony of the Rocks*, a polemical defender of theism and of revelation against some whom he regarded as their deadly assailants. It would have been safe and pleasant for Miller to waive all consideration of the religious question. He would thus have escaped the [illegible] sneer of the scientific expert. He would have escaped also the cold suspicion of many on his own side, for the great mass of mediocre religionists like nothing so well as the simple ignoring of difficulties and hushing up of objections. But he shrank instinctively from the moral cowardice of reserve. The advance of science has tended to compromise some of his controversial positions. When he occupied the chair of the Royal Physical Society of Edinburgh in 1852, he could look the most eminent representatives of contemporary geology in the face, and claim their assent to the possibility of drawing definite lines of demarcation between the Tertiary, Secondary, and Palæozoic strata. He could speak of the entire type of organic being as altering between these periods. "All on the one side of the gap," he could dare to affirm, "belongs to one fashion, and all on the other to another and wholly different fashion." In the thirty intervening years every form of the cataclysmal scheme of geological progression has been discredited. It has become impossible to obtain anything like a *consensus* of opinion among scientific men as to the placing of those frontier lines between period and period which, however wide may be the margins of gradation assigned to "morning" and "evening," are indispensable to the maintenance of Miller's theory of the six days' vision of creation. "Geographical provinces and zones," says Professor Huxley, "may have been as distinctly marked in the Palæozoic epoch as at present, and those seemingly sudden appearances of new genera and species which we ascribe to new creation may be simple results of migration." Such is now the received opinion of geologists, and we may be sure that Miller, who never shut his eyes to an established fact, would have accepted it. He has said in so many words that the Bible does not teach science.

In the long and memorable debate on the origin of species he strenuously engaged, maintaining against the author of the *Vestiges* the doctrine of specific creation. But when he did so he could feel that Buckland, Sedgwick, Murchison, and Lyell were on his side; nor is it a paradox to allege that he was an ally of Darwin himself. If the author of the *Vestiges* was right, Darwin was wrong. In point of fact the former was very nearly right; but, precisely because Darwin supplies what is lacking in his argument, those who intelligently assent to the *Origin of Species* are bound not to assent to the *Vestiges*.

But it is chiefly perhaps in connexion with the sweetness and classical animation of his style and the lovely views he gives of nature's facts that we ought to praise Hugh Miller. In an age prodigal of genius, yet abounding in extravagance, glare, and tinsel, the self-educated stonemason wrote with the calmness and moderation of Addison. His powerful imagination was disciplined to draw just those lines and to lay on just those colours which should reanimate the past. As his friend Carruthers, an admirable critic of style, observed, the fossil remains seem in his glowing pages to live and flourish, to fly, swim, or gambol, or to shoot up in vegetative profusion and splendour as in the primeval dawn of creation. Such power belongs to high genius. Tens of thousands he has invited to the study of nature; tens of thousands he has taught to find in geology no mere catalogue of defunct organisms, no dreary sermon in fossil stone, but a science of landscape as well as an intelligent understanding of the rocky framework of the world.

[illegible] peared *The Life and Letters of Hugh Miller*, by Peter Bayne ([illegible]n). Miller's works have circulated on the l[illegible] [illegible] widely read in America. They have been reprinted in the United States [illegible] of twenty volumes comprising the *Life and Letters*. ([illegible])

MILLER, William (1781–1849), the founder of an American religious sect holding peculiar millennarian views, was born at Pittsfield, Massachusetts, in 1781. He received a very imperfect education. In the war of 1812 he served as captain of volunteers on the Canadian frontier. While residing at Low Hampton, N.Y., he began in 1833 publicly to lecture on the subject of the millennium, asserting that the second coming of Christ would take place in about ten years. His doctrines awakened wide interest among certain classes of the community. In 1840 a semi-monthly journal, *The Signs of the Times*, was started by one of his followers, and two years later the *Advent Herald* made its appearance. About 1843 the second coming of Christ was expected by as many as 50,000 believers in the doctrines of Miller, and, although the disappointment of their hopes somewhat diminished their numbers, many continued their adherence to his tenets regarding the nature of the millennium. At present the number of Millerites or Adventists is estimated at from 15,000 to 20,000. Miller died at New Hampton, Washington county, N.Y., December 20, 1849.

MILLER, William (1796–1882), one of the greatest of modern line engravers, was born in Edinburgh on the 28th of May 1796. After studying in London under George Cook, a pupil of Basire's, he returned to his native city, where he continued to practise his art during a long lifetime. He executed plates after Thomson of Duddingston, Macculloch, D. O. Hill, Sir George Harvey, and other Scottish landscapists, but his most admirable and most voluminous works were his transcripts from Turner. The first of these was the Clovelly (1824), of *The Southern Coast*, a publication undertaken by his master and his brother William B. Cook, to which Miller also contributed the Combe Martin and the Portsmouth. He was engaged on the illustrations of *England and Wales*, 1827–38, of *The Rivers of France*, 1833–35, of Roger's *Poems*, 1834, and very largely on those of *The Prose and Poetical Works of Sir Walter Scott*, 1834. In *The Provincial Antiquities and Picturesque Scenery of Scotland*, 1826, he executed a few excellent plates after Thomson and Turner. Among his larger engravings of Turner's works may be mentioned The Grand Canal, Venice, The Rhine, Osterprey, and Feltzen, The Bell Rock, The Tower of London, and The Shepherd. The art of William Miller was warmly appreciated by Turner himself, and Mr Ruskin has pronounced him to be on the whole the most successful translator into line of the paintings of the greatest English landscapist. His renderings of complex Turnerian sky-effects are especially delicate and masterly. Towards the end of his life Miller abandoned engraving and occupied his leisure in the production of water colours, many of which were exhibited in the Royal Scottish Academy, of which he was an honorary member. He resumed his burin, however, to produce two final series of vignettes from drawings by Birket Foster illustrative of Hood's *Poems*, published by Moxon in 1871. Miller was a much respected member of the Society of Friends. He died while on a visit to Sheffield, on the 20th of January 1882.

MILLER'S THUMB (*Cottus gobio*), a well-known little fish, abundant in all rivers and lakes of northern and central Europe with clear water and gravelly bottom. The genus *Cottus*, to which the Miller's Thumb belongs, is easily recognized by its broad, flat head, rounded and scaleless body, large pectoral and narrow ventral fins, with two dorsal fins, the anterior shorter than the posterior; the præoperculum is armed with a simple or branched spine. The species of the genus *Cottus* are rather numerous, and are confined to the north temperate zone of the globe, the majority being marine, and known by the name of "Bull-heads." The Miller's Thumb is confined to fresh water, and only one other freshwater species is found in Europe, *C. pœcilopus*, from rivers of Hungary, Galicia, and the Pyrenees; some others occur in the fresh waters of northern Asia and North America. The Miller's Thumb is common in all suitable localities in Great Britain, but is extremely rare in Ireland; in the Alps it reaches to an altitude exceeding 7000 feet. Its usual length is from 3 to 5 inches. Generally hidden under a stone or in a hollow of the bank, it watches for its prey, which consists of small aquatic animals, and darts when disturbed with extraordinary rapidity to some other place of refuge. The female deposits her ova in a cavity under a stone, whilst the male watches and defends them until the young are hatched and able to shift for themselves.

MILLET (French, *millet*; Italian, *miglietto*, diminutive of *miglio* = Latin *mille*, a thousand, in allusion to its fertility) is a name applied with little definiteness to a considerable number of often very variable species of cereals belonging to distinct genera and even subfamilies of *Gramineæ* The true millet, however, is generally admitted to be *Panicum* (*Setaria*) *miliaceum*, L (German *Hirse*, with which *P miliare*, Lam, is reckoned by some botanists) It is indigenous to the East Indies and North Australia, but is mentioned by Hippocrates and Theophrastus as already cultivated in South Europe in their time Some suppose it to be one of the earliest grains used in bread-making, and ascribe the origin of its name to *panis*, bread, rather than to the paniculate inflorescence It is annual, requires rich but friable soil, grows to about 3 or 4 feet high, and is characterized by its bristly, much branched nodding panicles One variety has black grains It is largely cultivated in India, southern Europe, and northern Africa, and ripens as far north as southern Germany, in fact, wherever the climate admits of the production of wine The grain, which is very nutritious, is used in the form of groats, and makes excellent bread when mixed with wheaten flour It is also largely used for feeding poultry and cage birds, for which purpose mainly it is imported *P italicum*, L (*Setaria italica*, Beauv), is of similar origin and distribution, and is one of the most wholesome and palatable Indian cereals It is annual, grows 4 to 5 feet high, and requires dry light soil German Millet (*P germanicum*, German *Kolbenhirse*, *Mohar*) is probably merely a less valuable and dwarf variety of *P italicum*, having an erect, compact, and shorter spike The grains of both are very small only one half as long as those of common millet, but are exceedingly prolific Many stalks arise from a single root and a single spike often yields 2 oz of grain, the total yield being five times that of wheat They are imported for poultry feeding like the former species, but are extensively used in soups, &c, on the Continent Numerous other species belonging to this vast genus—the largest among grasses, of which the following are among the most important—are also cultivated in tropical or sub-tropical countries for their grain or as fodder grasses, or both, each variety of soil, from swamp to desert, having its characteristic forms They are very readily acclimatized wherever the temperature is sufficient, *e g*, in Australia, and seem destined to rise in agricultural importance

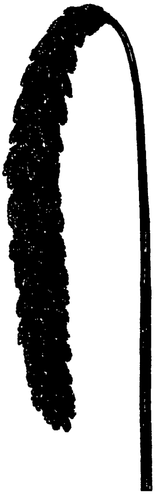


FIG 1 —*Panicum italicum*

Polish Millet is *P digitaria* *P frumentaceum* Roxb Shamalo a Deccan grass, is probably a native of tropical Africa while the perennial *P sarmentosum* Roxb, also largely cultivated in tropical countries, is from Sumatra *P decompositum* is the Australian millet, its grains being made into cakes by the aborigines *P maximum* Jacq is the Guinea Grass it is perennial grows 8 feet high, and yields abundance of highly nutritious grain *P spectabile* Nees, is the Coapim of Angola but has been acclimatized in Brazil and other tropical countries Other gigantic species 6 or 7 feet high form the field crops on the banks of the Amazons Of species belonging to allied genera, *Pennisetum thyphoideum* Rich (*Penicillaria spicata*, Willd), Bajree, sometimes also called Egyptian Millet, a Guinea corn is largely cultivated in tropical Asia Nubia and Egypt *P distichum* grows south of the Sahara Species of *Paspalum*, *Eleusine*, and *Milium* are also cultivated as millets.

But the most important dry grain of the tropical countries of Africa and Asia, particularly of India, is *Sorghum vulgare*, Pers. (*Holcus Sorghum*, L., *Andropogon Sorghum*, Roxb), Durra, Great Millet, Indian Millet, Turkish Millet, or Guinea Corn (the French *sorgho*, German *Mohrenhirse* or *Kaffernkorn*, Tamil *Cholum*, Bengalese *Jowari*) It ranges probably as extensively as wheat, being also largely cultivated in southern Europe, the United States, and the West Indies. In Asia Minor, Arabia, Italy, and Spain it may be said to replace oats and barley It is annual, and may reach 12 feet in height, it is extremely prolific, even rivalling maize, of which it is a near congener Its flour is very white, but does not easily make good bread, it is largely used in cakes and puddings and for feeding cattle and poultry The panicles are used for brooms, and the roots for velvet-brushes. *S bicolor*, *S nigrum*, *S rubrum*, *S Kaffrorum* (Kaffre Corn), *S saccharatum*, and other species or varieties are also of economic importance the last-named (the "Chinese sugar-cane) being much cultivated in the United States as a source of molasses, the juice, which contains much glucose but comparatively little cane sugar, being simply expressed and concentrated by evaporation *S vulgare* is the grain referred to by Pliny as millet

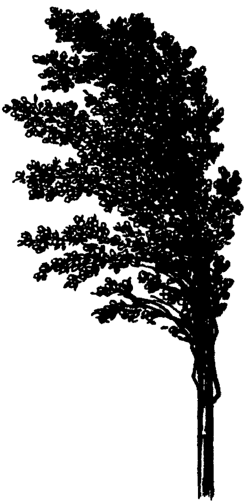


FIG 2 —*Sorghum vulgare*

For systematic and economic purposes see GRASSES, Luerssen, *Med Pharm Botanik* Leipsic 1880 Drury *Useful Plants of India* London 1873 F v Muller *Select Plants for Naturalisation in Victoria* Melbourne 1876 For archæology, see Hehn s *Kulturpflanzen*, &c Berlin 1877 On *Sorghum cernuum* ("rice corn &c of western Kansas) see Drummond s ' Report in *Parl Papers* No 2570 (1880)

MILLET, JEAN FRANÇOIS (1814–1875), was a painter of French peasant life, and it may be questioned whether France has produced in our day any greater or more original artist He himself came of a peasant family, and was born on the 4th of October 1814 in the hamlet of Gruchy, near Gréville (La Manche), in the wild and picturesque district called La Hague His boyhood was passed working in his father s fields, but the sight of the engravings in an old illustrated Bible set him drawing, and thenceforth, whilst the others slept, the daily hour of rest was spent by Millet in trying to render the familiar scenes around him From the village priest the lad learnt to read the Bible and Virgil in Latin, and acquired an interest in one or two other works of a high class which accompanied him through life, he did not, however, attract attention so much by his acquirements as by the stamp of his mind The whole family seems, indeed, to have worn a character of austerity and dignity, and when Millet's father finally decided to test the vocation of his son as an artist, it was with a gravity and authority which recalls the patriarchal households of Calvinist France. Two drawings were prepared and placed before a painter at Cherbourg named Mouchel, who at once recognized the boy s gifts, and accepted him as a pupil, but shortly after (1835) Millet's father died, and the eldest son, with heroic devotion, took his place at home, nor did he return to his work until the pressing calls from without were solemnly enforced by the wishes of his own family He accordingly went back to Cherbourg, but after a short time spent there with another master (Langlois) started with many misgivings for Paris The council general of the department had granted him a sum of 600 francs, and the town council promised an annual pension of 400, but in spite of friendly help and introductions Millet went through great difficulties The system of the École des Beaux Arts was hateful to him, and it was not until after much hesitation that he decided to enter an official studio—that of Delaroche The master was certainly puzzled by his pupil, he saw his ability, and, when Millet in his poverty could not longer pay the monthly fees, arranged for his free admission to the studio, but he tried in vain to make him take the approved direction, and lessons ended with "Eh, bien, allez à votre guise, vous êtes si nouveau pour moi que je ne veux rien vous dire." At last, when the competition for the Grand Prix came on, Delaroche gave Millet to understand that he intended to secure the nomination of another, and thereupon Millet withdrew himself, and with his friend Marolle started in a little studio in the Rue de l Est He had renounced the beaten track, but he continued to study hard whilst he sought to procure bread by painting portraits at 10 or 15 francs a piece and producing small "pastiches" of Watteau and Boucher These works are classed as those of his "flowery manner," and Millet has been reproached—he whose whole life was an act of conviction—with having sacrificed his convictions to curry favour with the public It is true that he himself has recorded his aversion to both these masters "In the Louvre," he said, "I received vivid impressions from Mantegna, complete from Michelangelo, after Michelangelo and Poussin I have remained faithful to the early masters" Boucher was for him an object of "repulsion," and in Watteau "I saw," he said, "a little theatrical world which oppressed me" Thus it was then that Millet naturally felt and saw, but the strongest genius knows moments of self-doubt Later in life Millet was heard to say that were it not for the small group who believed in him he should have lost faith in himself In earlier years, before he was certain of his own leading, he was naturally influenced by the advice of others whose arguments were enforced by the pressure of dire poverty Even so from time to time the native vein showed strong In 1840, as soon as he had despatched a portrait to the Salon, Millet went back to Gréville, where he painted Sailors Mending a Sail and a few other pictures—reminiscences of Cherbourg life His first success was obtained in 1844 when his Milkwoman and Lesson in Riding (pastel) attracted notice at the Salon, and friendly artists presented themselves at his lodgings only to learn that his wife had just died, and that he himself had disappeared Millet was at Cherbourg, there he remarried, but having amassed a few hundred francs he went back to Paris and presented his St Jerome at the Salon of 1845 This picture was rejected and exists no longer, for Millet, short of canvas, painted over it Œdipus Unbound, a work which during the following year was the object of violent criticism He was, however, no longer alone, Diaz, Eugène Tourneux, Rousseau, and other men of note supported him by their confidence and friendship, and he had by his side the brave Catharine Lemaire, his second wife, a woman who bore poverty with dignity and gave courage to her husband through the cruel trials in which he penetrated by a terrible personal experience the bitter secrets of the very poor To this date belong Millet's Golden Age, Bird Nesters, Young Girl and Lamb, and Bathers, but to the Bathers (Louvre) succeeded The Mother Asking Alms, The Workman's Monday, and The Winnower This last work, exhibited in 1848, obtained conspicuous success, but did not sell till Ledru Rollin, informed of the painter's dire distress, gave him 500 francs for it, and accompanied the purchase with a commission, the money for which enabled Millet to leave Paris for Barbizon, a village on the skirts of the forest of Fontainebleau. There he settled in a three-roomed cottage for the rest of his life—twenty-seven years, in which he wrought out the perfect story of that peasant life of which he alone has given a "complete impression" Jules Breton has coloured the days of toil with sentiment, others, like Courbet, whose eccentric Funeral at Ornans attracted more notice at the Salon of 1850 than Millet's Sowers and Binders, have treated similar subjects as a vehicle for protest against social misery, Millet alone, a peasant and a miserable one himself, saw true, neither softening nor exaggerating what he saw In a curious letter written to M Sensier at this date (1850) Millet expressed his resolve to break once and for all with mythological and undraped subjects, and the names of the principal works painted subsequently will show how stedfastly this resolution was kept In 1852 he produced Girls Sewing, Man Spreading Manure, 1853, The Reapers, 1854, Church at Gréville (Luxembourg), 1855—the year of the International Exhibition, at which he received a medal of second class—Peasant Grafting a Tree, 1857, The Gleaners, 1859, The Angelus (Louvre, engraved Waltner), The Woodcutter and Death, 1860, Sheep Shearing, 1861, Woman Shearing Sheep, Woman Feeding Child, 1862, Potato Planters, Winter and the Crows, 1863, Man with Hoe, Woman Carding, 1864, Shepherds and Flock, Peasants Bringing Home a Calf Born in the Fields, 1869, Knitting Lesson, 1870, Buttermaking, 1871, November—recollection of Gruchy Any one of these works will show how great an influence Millet s previous practice in the nude had upon his style The dresses worn by his figures are not clothes, but drapery through which the forms and movements of the body are strongly felt, and their contour shows a grand breadth of line which strikes the eye at once Something of the imposing unity of his work was also, no doubt, due to an extraordinary power of memory, which enabled Millet to paint (like Horace Vernet) without a model, he could recall with precision the smallest details of attitudes or gestures which he proposed to represent Thus he could count on presenting free from after thoughts the vivid impressions which he had first received, and Millet's nature was such that the impressions which he received were always of a serious and often of a noble order, to which the character of his execution responded so perfectly that even a Washerwoman at her Tub will show the grand action of a Medea The drawing of this subject is reproduced in *Souvenirs de Barbizon*, a pamphlet in which M. Piédagnel has recorded a visit paid to Millet in 1864. His circumstances were then less evil, after struggles as severe as those endured in Paris A contract by which he bound himself in 1860 to give up all his work for three years had placed him in possession of 1000 francs a month His fame extended, and at the exhibition of 1867 he received a medal of the first class, and the ribbon of the Legion of Honour, but he was at the same moment deeply shaken by the death of his faithful friend Rousseau. Though he rallied for a time he never completely recovered his health, and on the 20th January 1875 he died He was buried by his friend's side in the churchyard of Chailly.

See A. Sensier, *Vie et Œuvre de J F Millet*, 1874, Piédagnel, *Souvenirs de Barbizon*, &c (E. F S. P.)

MILLVILLE, a city of the United States, in Cumberland county, New Jersey, at the head of navigation of Maurice river, 40 miles by rail from Philadelphia by the Cape May, Millville, and Vineland section of the West Jersey Railroad.

It is one of the chief seats of glass-making in the State, and also manufactures cotton, iron pipes for water and gas, turbines, &c. The population was 7660 in 1880.

MILMAN, Henry Hart (1791–1868), dean of St Paul's, was born February 10, 1791, and was the third son of Sir Francis Milman, physician to George III. He was educated at Eton and at Brasenose College, Oxford; his university career was brilliant, and among other distinctions he gained the Newdigate prize with a poem on the Apollo Belvedere. In 1816 he was ordained, and was soon afterwards presented to the living of St Mary's, Reading. He had already made his appearance as a dramatic writer, his tragedy of *Fazio*, founded on a narrative in the *Annual Register* for 1795, having been brought on the stage without his knowledge under the title of *The Italian Wife*. It was subsequently produced at Covent Garden, and obtained great success from the acting of Miss O'Neill as Bianca. The merit of the play consists chiefly in the powerful situation; the diction is florid and ornate. The same criticism, by the author's own confession, applies to his epic, *Samor, the Lord of the Bright City* (Gloucester), a poem written in early youth. The subject is taken from British legend, and Milman has failed to invest it with serious interest. He was more successful in his next attempts, where the subjects were well adapted to an imagination easily kindled by the historical or the moral picturesque. The death struggle of an expiring nation in the *Fall of Jerusalem* (1820), the conflict of new truth and old order, of religious enthusiasm and earthly affection, in the *Martyr of Antioch* (1822), are depicted with great eloquence and real insight into human nature. Milman's characters, however, are personified tendencies rather than personages, and in poetical style he was unable to free himself from the influence of Byron. *Belshazzar* (1822) is in general a pale copy of Byron's *Sardanapalus*, but contains some fine lyrics. Milman's lyrics, indeed, especially his hymns, have frequently a fine ring and sweep, though the thought is generally commonplace. His tragedy of *Anne Boleyn* (1826) is a poor performance. With the exception of admirable versions of the Sanskrit episode of Nala and Damayanti, and of the *Agamemnon* and *Bacchæ*, this was Milman's last poetical work. He was elected professor of poetry at Oxford, and in 1827 delivered the Bampton lectures, selecting as his subject the conduct and character of the apostles as an evidence of Christianity. In 1830 his *History of the Jews* appeared in the Family Library. The contracted limits of this series forbade any adequate treatment of the subject; the work is nevertheless memorable as the first by an English clergyman which treated the Jews as an Oriental tribe, recognized sheikhs and emirs in the Old Testament, sifted and classified documentary evidence, and evaded or minimized the miraculous. Milman was violently attacked, especially by Dr Faussett and Bishop Mant, and the odium thus occasioned stopped the publication of the Family Library, and long impeded the preferment of the writer. In 1835, however, Sir Robert Peel made him rector of St Margaret's and canon of Westminster, and in 1849 he became dean of St Paul's. The unpopularity attaching to him had by this time nearly died away; and now, generally revered and beloved, intimate with men of all pursuits, politics, and persuasions, counted among the chief ornaments of the most polished society of the metropolis, he occupied a singularly dignified and enviable position, which he constantly employed for the promotion of culture and enlightenment, and in particular for the relaxation of subscription to ecclesiastical formularies. His *History of Christianity under the Empire* had appeared in 1840, but had been as completely ignored as if, said Lord Melbourne, the clergy had taken a universal oath never to mention it to any one. Widely different was the reception of the continuation, his great *History of Latin Christianity* to the death of Pope Nicholas V., which appeared in 1855. He also edited Gibbon and Horace, and at his death in 1868 left behind him almost finished a delightful history of his own cathedral, which was completed and published by his son.

Milman possessed a large share of the imagination which enters into and calls up the past, and of that which interprets actions and apprehends opinions by the power of sympathy. In creative imagination he was deficient, a defect which alone prevented him from attaining the first rank as an historian. His pages are crowded with splendid names rather than with living personages; the springs of action are disclosed with remarkable penetration, but the actor himself is rather heard than seen. There are, however, exceptions, such as his portrait of Sir Christopher Wren; and he possessed a peculiar power of investing mere intellectual tendencies with personality and life. His parallel of Latin and Teutonic Christianity, for example, is a piece of finished historical character painting. His power of sympathy rendered him in effect, as his natural equity and benignity made him in intention, a model of historical candour, only chargeable, perhaps, with too much gentleness. It will be long ere his great work is superseded; but he will perhaps be remembered even longer as an embodiment of all the qualities which the higher ecclesiastical preferment can be supposed capable of encouraging or rewarding among the clergy of a great historical church. (R. G.)

MILO, one of the most famous athletes of Greece, whose name became proverbial for personal strength. He lived about the end of the 6th century B.C., was six times crowned at the Olympic games and six times at the Pythian for wrestling, and was famous throughout the civilized world for his feats of strength, such as carrying an ox on his shoulders through the stadium at Olympia. In his native city of Crotona he was much honoured, and he commanded the army which defeated the people of Sybaris in 511 B.C. When Democedes, the physician of Darius, deserted the Persian service, he sent a boastful message to the king of Persia informing him of his marriage to the daughter of Milo. The traditional account of his death is often used to point a moral: he found a tree which some woodcutters had partially split with a wedge, and attempted to rend it asunder; but the wedge fell out, and the tree closed on his hand, imprisoning him till wolves came and devoured him.

MILO was the surname of T. Annius Papianus, one of the best-known of the partisan leaders and ruffians in the stormy times that preceded the dissolution of the Roman republic. His father was C. Papius Celsus, but he was adopted by his mother's father T. Annius Luscus. He joined the Pompeian party, and led the band of mercenaries and gladiators which was required to defend the cause and its chief supporters in the public streets. P. Clodius, the leader of the ruffians who professed the democratic cause, was his personal enemy, and their brawls in the streets and their mutual accusations in the law courts lasted for several years, beginning when Milo was tribune of the commons in 57 B.C. In 53 their quarrels came to a height when Milo was candidate for the consulship and Clodius for the prætorship; and when the two leaders met by accident on the Appian Way at Bovillæ, Clodius was murdered (January 20, 52 B.C.). This act of violence strengthened the hands of Pompey, who was nominated sole consul, and proposed several stringent laws to restore order in the city. Milo was impeached; his guilt was clear, and his enemies took every means of intimidating his supporters and his judges. Cicero was afraid to deliver the speech he had prepared *Pro Milone*, and the extant oration is an expanded form of the unspoken defence. Milo went into exile at Massilia, and his property was sold by auction. He joined the insurrection of M. Cælius in 48 B.C., and was soon slain near Thurii in Lucania. His wife Fausta was daughter of the dictator Sulla.

MILTIADES. See Greece, vol. xi. p. 99.

MILTON, JOHN (1608–1674), was born in Bread Street, Cheapside, London, on the 9th of December 1608 His father, known as Mr John Milton of Bread Street, scrivener, was himself an interesting man He was a native of Oxfordshire, having been born there in or about 1563, the son of a Richard Milton, yeoman of Stanton St-John's, of whom there are traces as one of the sturdiest adherents to the old Roman Catholic religion that had been left in his district The son, however, had turned Protestant, and, having been cast off on that account, had come to London, apparently about the year 1586, to push his fortune Having received a good education, and having good abilities, especially in music, he may have lived for some time by musical teaching and practice Not till 1595, at all events, when he was long past the usual age of apprenticeship, do we hear of his preparation for the profession of a scrivener, and not till February 1599–1600, when he was about thirty seven years of age, did he enter the profession as a qualified member of the Scriveners' Company It was then that he set up his "house and shop' in Bread Street, and began, like other scriveners, his lawyerly business of drawing up wills, marriage settlements, and the like, with such related business as that of receiving money from clients for investment and lending it out to the best advantage It was at the same time that he married Till recently there has been the most extraordinary uncertainty as to the maiden name of his wife, the mother of the poet It has been now ascertained, however, that she was a Sarah Jeffrey, one of the two orphan daughters of a Paul Jeffrey, of St Swithin's, London, "citizen and merchant taylor,' originally from Essex, who had died before 1583 At the date of her marriage she was about twenty eight years of age Her widowed mother, Mrs Ellen Jeffrey, came to reside in the house in Bread Street, and died there in February 1610–11 Before this death of the maternal grandmother three children had been born to the scrivener and his wife, of whom only two survived,—the future poet, and an elder sister, called Anne Of three more children, born subsequently, only one survived,—Christopher, the youngest of the family, born December 3, 1615

The first sixteen years of Milton's life coinciding exactly with the last sixteen of the reign of James I, associate themselves with the house in Bread Street, and with the surroundings of that house in Old London His father, while prospering in business, continued to be known as a man of "ingeniose' tastes, and even acquired some distinction in the London musical world of that time by his occasional contributions to important musical publications Music was thus a part of the poet's domestic education from his infancy Whatever else could be added was added without stint Again and again Milton speaks with gratitude and affection of the ungrudging pains bestowed by his father on his early education "Both at the grammar school and also under other masters at home," is the statement in one passage, "he caused me to be instructed daily" This brings us to about the year 1619, when Milton was ten years of age At that time his domestic tutor was Thomas Young, a Scotsman from Perthshire, and graduate of the university of St Andrews, afterwards a man of no small distinction among the English Puritan clergy, but then only curate or assistant to some parish clergyman in or near London, and eking out his livelihood by private teaching Young's tutorship lasted till 1622, when he was drawn abroad by an offer of the pastorship or chaplaincy to the congregation of English merchants in Hamburg Already, however, for a year or two, his tutorship had been only supplementary to the education which the boy was receiving by daily attendance at St Paul's public school, close to Bread Street The headmaster of the school was Mr Alexander Gill, an elderly Oxford divine, of high reputation for scholarship and teaching ability Under him, as usher or second master, was his son, Alexander Gill the younger, also an Oxford graduate of scholarly reputation, but of blustering character. Milton's acquaintanceship with this younger Gill, begun at St Paul's school, led to subsequent friendship and correspondence Far more affectionate and intimate was the friendship formed by Milton at St Paul's with a certain young Charles Diodati, his schoolfellow there, the son of a naturalized Italian physician, Dr Theodore Diodati, who had settled in London in good medical practice, and was much respected, both on his own account, and as being the brother of the famous Protestant divine, Jean or Giovanni Diodati of Geneva Young Diodati, who was destined for his father's profession, left the school for Oxford University early in 1623, but Milton remained till the end of 1624. A family incident of that year was the marriage of his elder sister, Anne, with Edward Phillips, a clerk in the Government office called the Crown Office in Chancery. Milton had then all but completed his sixteenth year, and was as scholarly, as accomplished, and as handsome a youth as St Paul's school had sent forth We learn from himself that his exercises "in English or other tongue, prosing or versing, but chiefly this latter," had begun to attract attention even in his boyhood This implies that he must have had a stock of attempts in English and Latin by him of earlier date than 1624 Of these the only specimens that now remain are his *Paraphrase on Psalm CXIV* and his *Paraphrase on Psalm CXXXVI*

On February 12, 1624–25, Milton, at the age of sixteen years and two months, was entered as a student of Christ's College, Cambridge, in the grade of a "Lesser Pensioner" His matriculation entry in the books of the university is two months later, April 9, 1625 Between these two dates James I had died, and had been succeeded by Charles I

Cambridge University was then in the full flush of its prosperity on that old system of university education which combined Latin and Greek studies with plentiful drill and disputation in the scholastic logic and philosophy, but with little of physical science, and next to no mathematics There were sixteen colleges in all, dividing among them a total of about 2900 members of the university Christ's College, to which Milton belonged, ranked about third in the university in respect of numbers, counting about 265 members on its books The master was Dr Thomas Bainbrigge, and among the thirteen fellows were Mr Joseph Meade, still remembered as a commentator on the Apocalypse, and Mr William Chappell, afterwards an Irish bishop It was under Chappell's tutorship that Milton was placed when he first entered the college At least three students who entered Christ's after Milton, but during his residence, deserve mention One was Edward King, a youth of Irish birth and high Irish connexions, who entered in 1626, at the age of fourteen, another was John Cleveland, afterwards known as royalist and satirist, who entered in 1627, and the third was Henry More, subsequently famous as the Cambridge Platonist who entered in 1631, just before Milton left Milton's own brother, Christopher, joined him in the college in February 1630–31, at the age of fifteen

Milton's academic course lasted seven years and five months, or from February 1624–25 to July 1632, bringing him from his seventeenth year to his twenty fourth The first four years were his time of undergraduateship It was in the second of these, the year 1626, that there occurred that quarrel between him and his tutor, Mr Chappell, which Dr Johnson, making the most of a lax tradition from Aubrey, magnified into the supposition that Milton may have been one of the last students in either of the English universities that suffered the indignity of corporal punishment. The legend deserves no credit, but it is certain that Milton, on account of some disagreement with Chappell, leading to the interference of Dr Bainbrigge, left college for a time, and that, when he did return, it was under an arrangement which, while securing that he should not lose a term by his absence, transferred him from the tutorship of Chappell to that of Mr Nathaniel Tovey, another of the fellows of Christ's. From a reference to the matter in the first of the Latin elegies one infers that the cause of the quarrel was some outbreak of self-assertion on Milton's part. We learn indeed, from words of his own elsewhere, that it was not only Chappell and Bainbrigge that he had offended by his independent demeanour, but that, for the first two or three years of his undergraduateship, he was generally unpopular, for the same reason, among the younger men of his college. They had nicknamed him "The Lady," a nickname which the students of the other colleges took up, converting it into "The Lady of Christ's College", and, though the allusion was chiefly to the peculiar grace of his personal appearance, it conveyed also a sneer at what the rougher men thought his unusual prudishness, the haughty fastidiousness of his tastes and morals. Quite as distinct as the information that he was for a while unpopular with the majority of his fellow students are the proofs that they all came round him at last with respect and deference. The change had certainly occurred before January 1628–29, when, at the age of twenty, he took his B.A. degree. By that time his intellectual pre-eminence in his college, and indeed among his coevals in the whole university, had come to be acknowledged. His reputation for scholarship and literary genius, extraordinary even then, was more than confirmed during the remaining three years and a half of his residence in Cambridge. A fellowship in Christ's which fell vacant in 1630 would undoubtedly have been his had the election to such posts depended then absolutely on merit. As it was, the fellowship was conferred, by royal favour and mandate, on Edward King, his junior in college standing by sixteen months. In July 1632 Milton completed his career at the university by taking his M.A. degree. His signature in the University Register stands at the head of the list of those who graduated as masters that year from Christ's. Anthony Wood's summary of the facts of his university career as a whole is that he "performed the collegiate and academical exercises to the admiration of all, and was esteemed to be a virtuous and sober person, yet not to be ignorant of his own parts." The statement is in perfect accordance with Milton's own account. He speaks of "a certain niceness of nature, an honest haughtiness, and self-esteem of what I was or what I might be," as one of his earliest characteristics, and, though intimating that, even while actually a student at Cambridge, he had "never greatly admired" the system of the place, he leaves us in no doubt as to the quite exceptional applause with which he had gone through all the prescribed work. To the regular Latin and Greek of the university he had added, he tells us, French, Italian, and Hebrew. He had also learnt fencing and other gentlemanly exercises of the time, and was an expert swordsman.

Of Milton's skill at Cambridge in what Wood calls "the collegiate and academical exercises" specimens remain in his *Prolusiones Quædam Oratoriæ*. They consist of seven rhetorical Latin essays, generally in a whimsical vein, delivered by him, in his undergraduateship or during his subsequent bachelorship in arts, either in the hall of Christ's College or in the public University School. Relics of Milton's Cambridge period are also four of his Latin *Familiar Epistles*, but more important are the poetical remains. These include the greater number of his preserved Latin poems—to wit, (1) the seven pieces which compose his *Elegiarum Liber*, two of the most interesting of them addressed to his medical friend, Charles Diodati, and one to his former tutor Young in his exile at Hamburg, (2) the five short Gunpowder Plot epigrams, now appended to the *Elegies*, and (3) the first five pieces of the *Sylvarum Liber*, the most important of which are the hexameter poem "In Quintum Novembris" and the piece entitled "Naturam non pati senium." Of the English poems of the Cambridge period the following is a dated list:—*On the Death of a Fair Infant*, 1625–26, the subject being the death in that inclement winter of his infant niece, the first-born child of his sister Mrs Phillips, *At a Vacation Exercise in the College*, 1628, the magnificent Christmas ode *On the Morning of Christ's Nativity*, 1629, the fragment called *The Passion* and the *Song on May Morning*, both probably belonging to 1630, the lines *On Shakespeare*, certainly belonging to that year, the two facetious pieces *On the University Carrier*, 1630–31, the *Epitaph on the Marchioness of Winchester*, 1631, the sonnet *To the Nightingale*, probably of the same year, the sonnet *On arriving at the Age of twenty three*, dating itself certainly in December 1631.

Just before Milton quitted Cambridge, his father, then verging on his seventieth year, had practically retired from his Bread Street business, leaving the active management of it to a partner, named Thomas Bower, a former apprentice of his, and had gone to spend his declining years at Horton in Buckinghamshire, a small village near Colnbrook, and not far from Windsor. Here, accordingly, in a house close to Horton church, Milton mainly resided for the next six years,—from July 1632 to April 1638.

Although, when he had gone to Cambridge, it had been with the intention of becoming a clergyman, that intention had been abandoned. His reasons were that "tyranny had invaded the church," and that, finding he could not honestly subscribe the oaths and obligations required, he "thought it better to preserve a blameless silence before the sacred office of speaking begun with servitude and forswearing." In other words, he was disgusted with the system of high prelacy which Laud, who had been bishop of London and minister paramount in ecclesiastical matters since 1628, was establishing and maintaining in the Church of England. "Church outed by the prelates," as he emphatically expresses it, he seems to have thought for a time of the law. From that too he recoiled, and, leaving the legal profession for his brother Christopher, he had decided that the only life possible for himself was one of leisurely independence, dedicated wholly to scholarship and literature. His compunctions on this subject, expressed already in his sonnet on arriving at his twenty-third year, are expressed more at length in an English letter sent by him, shortly after the date of that sonnet, and with a copy of the sonnet included, to some friend who had been remonstrating with him on his "belatedness" and his persistence in a life of mere dream and study. There were gentle remonstrances also from his excellent father. Between such a father and such a son, however, the conclusion was easy. What it was may be learnt from Milton's fine Latin poem *Ad Patrem*. There, in the midst of an enthusiastic recitation of all that his father had done for him hitherto, it is intimated that the agreement between them on their one little matter of difference was already complete, and that, as the son was bent on a private life of literature and poetry, it had been decided that he should have his own way, and should in fact, so long as he chose, be the master of his father's means and the chief person in the Horton household. For the six years from 1632 thus, accordingly, was Milton's position. In perfect leisure, and in a pleasant rural retirement, with Windsor at the distance of an easy walk, and London only about 17 miles off, he went through, he tells us, a systematic course of reading in the Greek and Latin classics, varied by mathematics, music, and the kind of physical science we should now call cosmography.

It is an interesting fact that Milton's very first public appearance in the world of English authorship was in so honourable a place as the second folio edition of *Shakespeare* in 1632. His enthusiastic eulogy on Shakespeare, written in 1630, was one of three anonymous pieces prefixed to that second folio, along with reprints of the commendatory verses that had appeared in the first folio, one of them Ben Jonson's immortal tribute to Shakespeare's memory. Among the poems actually written by Milton at Horton the first, in all probability, after the Latin hexameters *Ad Patrem*, were the exquisite companion pieces *L'Allegro* and *Il Penseroso*. There followed, in or about 1633, the fragment called *Arcades*. It was part of a pastoral masque got up by the young people of the noble family of Egerton in honour of their venerable relative the countess dowager of Derby, and performed before that lady at her mansion of Harefield, near Uxbridge, about 10 miles from Horton. That Milton contributed the words for the entertainment was, almost certainly, owing to his friendship with Henry Lawes, one of the chief court musicians of that time, whose known connexion with the Egerton family points him out as the probable manager of the Harefield masque. Next in order among the compositions at Horton may be mentioned the three short pieces, *At a Solemn Music*, *On Time*, and *Upon the Circumcision*; after which comes *Comus*, the largest and most important of all Milton's minor poems. The name by which that beautiful drama is now universally known was not given to it by Milton himself. He entitled it, more simply and vaguely, "A Masque presented at Ludlow Castle, 1634, before the Earl of Bridgewater, Lord President of Wales." The existence of this poem is certainly due to Milton's intimacy with Lawes. The earl of Bridgewater, the head of the Egerton family, had been appointed to the high office of the presidency or viceroyalty of Wales, the official seat of which was Ludlow in Shropshire; it had been determined that among the festivities on his assumption of the office there should be a great masque in the hall of Ludlow Castle, with Lawes for the stage manager and one of the actors; Milton had been applied to by Lawes for the poetry; and, actually, on Michaelmas night, September 29, 1634, the drama furnished by Milton was performed in Ludlow Castle before a great assemblage of the nobility and gentry of the Welsh principality, Lawes taking the part of "the attendant spirit," while the parts of "first brother," "second brother," and "the lady" were taken by the earl's three youngest children, Viscount Brackley, Mr Thomas Egerton, and Lady Alice Egerton.—From September 1634 to the beginning of 1637 is a comparative blank in our records. Straggling incidents in this blank are a Latin letter of date December 4, 1634, to Alexander Gill the younger, a *Greek Translation of Psalm CXIV*, a visit to Oxford in 1635 for the purpose of incorporation in the degree of M.A. in that university, and the beginning in May 1636 of a troublesome lawsuit against his now aged and infirm father.—The lawsuit, which was instituted by a certain Sir Thomas Cotton, baronet, nephew and executor of a deceased John Cotton, Esq., accused the elder Milton and his partner Bower, or both, of having, in their capacity as scriveners, misappropriated divers large sums of money that had been entrusted to them by the deceased Cotton to be let out at interest. The lawsuit was still in progress when, on the 3d of April 1637, Milton's mother died, at the age of about sixty-five. A flat blue stone, with a brief inscription, visible on the chancel pavement of Horton church, still marks the place of her burial. Milton's testimony to her character is that she was a "a most excellent mother and particularly known for her charities through the neighbourhood." The year 1637 was otherwise eventful in his biography. It was in that year that his *Comus*, after lying in manuscript for more than two years, was published by itself, in the form of a small quarto of thirty five pages. The author's name was withheld, and the entire responsibility of the publication was assumed by Henry Lawes. Milton seems to have been in London when the little volume appeared. He was a good deal in London, at all events, during the summer and autumn months immediately following his mother's death. The plague, which had been on one of its periodical visits of ravage through England since early in the preceding year, was then especially severe in the Horton neighbourhood, while London was comparatively free. It was probably in London that Milton heard of the death of young Edward King of Christ's College, whom he had left as one of the most popular of the fellows of the college, and one of the clerical hopes of the university. King had sailed from Chester for a vacation visit to his relatives in Ireland, when, on the 10th of August, the ship, in perfectly calm water, struck on a rock and went down, he and nearly all the other passengers going down with her. There is no mention of the sad accident in two otherwise very interesting Latin *Familiar Epistles* of Milton, of September 1637, both addressed to his medical friend Charles Diodati, and both dated from London; but how deeply the death of King had affected him appears from his occupation shortly afterwards. In November 1637, and probably at Horton, whence the plague had by that time vanished, he wrote his matchless pastoral monody of *Lycidas*. It was his contribution to a collection of obituary verses, Greek, Latin, and English, which King's numerous friends, at Cambridge and elsewhere, were getting up in lamentation for his sad fate. The collection did not appear till early in 1638, when it was published in two parts, with black bordered title pages, from the Cambridge University press, one consisting of twenty three Latin and Greek pieces, the other of thirteen English pieces, the last of which was Milton's monody, signed only with his initials "J. M." It was therefore early in 1638, when Milton was in his thirtieth year, that copies of his *Lycidas* may have been in circulation among those who had already become acquainted with his *Comus*.

Milton was then on the wing for a foreign tour. He had long set his heart on a visit to Italy, and circumstances now favoured his wish. The vexatious Cotton lawsuit, after hanging on for nearly two years, was at an end, as far as the elder Milton was concerned, with the most absolute and honourable vindication of his character for probity, though with some continuation of the case against his partner, Bower. Moreover, Milton's younger brother, Christopher, though but twenty two years of age, and just about to be called to the bar of the Inner Temple, had married a wife; and the young couple had gone to reside at Horton to keep the old man company. There being nothing then to detain Milton, all was arranged for his journey. Before the end of April 1638 he was on his way across the Channel, taking one English man servant with him. At the time of his departure the last great news in England was that of the National Scottish Covenant, or solemn oath and band of all ranks and classes of the Scottish people to stand by each other the death in resisting the ecclesiastical innovations which Laud and Charles had been forcing upon Scotland. To Charles the news of this "damnable Covenant," as he called it, was enraging beyond measure; but to the mass of the English Puritans it was far from unwelcome, promising, as it seemed to do, for England herself, the subversion at last of that system of "Thorough," or despotic government by the king and his ministers without parliaments, under which the country had been groaning since the contemptuous dissolution of Charles's third parliament ten years before.

Through Paris, where Milton made but a short stay, receiving polite attention from the English ambassador, Lord Scudamore, and having the honour of an introduction to the famous Hugo Grotius, then ambassador for Sweden at the French court, he moved on rapidly to Italy, by way of Nice. After visiting Genoa, Leghorn, and Pisa, he arrived at Florence, August 1638. Enchanted by the city and its society, he remained there two months, frequenting the chief academies or literary clubs, and even taking part in their proceedings. Among the Florentines with whom he became intimate were Jacopo Gaddi, young Carlo Dati, Pietro Frescobaldi, Agostino Coltellini, the grammarian Benedetto Buommattei, Valerio Chimentelli, and Antonio Francini. It was in the neighbourhood of Florence also that he "found and visited" the great Galileo, then old and blind, and still nominally a prisoner to the Inquisition for his astronomical heresy. From Florence, by Siena, Milton went to Rome. He reached the Eternal City some time in October, and spent about another two months there, not only going about among the ruins and antiquities and visiting the galleries, but mixing also, as he had done in Florence, with the learned society of the academies. Among those with whom he formed acquaintance in Rome were the German scholar, Lucas Holstenius, librarian of the Vatican, and three native Italian scholars, named Cherubini, Salzilli, and Selvaggi. There is record of his having dined once, in company with several other Englishmen, at the hospitable table of the English Jesuit College. The most picturesque incident, however, of his stay in Rome was his presence at a great musical entertainment in the palace of Cardinal Francesco Barberini. Here he had not only the honour of a specially kind reception by the cardinal himself, but also, it would appear, the supreme pleasure of listening to the marvellous Leonora Baroni, the most renowned singer of her age. Late in November he left Rome for Naples. Here also he was fortunate. The great man of the place was the now very aged Giovanni Battista Manso, marquis of Villa, the friend and biographer of the great Tasso, and subsequently the friend and patron of the sweet Marini. By a happy accident Milton obtained an introduction to Manso, and nothing could exceed the courtesy of the attentions paid by the aged marquis to the young English stranger. He had hardly been in Naples a month, however, when there came news from England which not only stopped an intention he had formed of extending his tour to Sicily and thence into Greece, but urged his immediate return home. "The sad news of civil war in England," he says, "called me back; for I considered it base that, while my fellow-countrymen were fighting at home for liberty, I should be travelling abroad for intellectual culture." In December 1638, therefore, he set his face northwards again. His return journey, however, probably because he learnt that the news he had first received was exaggerated or premature, was broken into stages. He spent a second two months in Rome, ascertained to have been January and February 1638–39; during which two months, as he tells us, he was in some danger from the papal police, because the English Jesuits in Rome had taken offence at his habit of free speech, wherever he went, on the subject of religion. Though he did not alter his demeanour in the least in this particular, nothing happened; and from Rome he got safely to Florence, welcomed back heartily by his Florentine friends, and renewing his meetings with them privately and in their academies. His second visit to Florence, including an excursion to Lucca, extended over two months; and not till April 1639 did he take his leave, and proceed, by Bologna and Ferrara, to Venice. About a month was given to Venice; and thence, having shipped for England the books he had collected in Italy, he went on, by Verona and Milan, over the Alps, to Geneva. In this Protestant city he spent a week or two in June, forming interesting acquaintanceships there too, and having daily conversations with the great Protestant theologian Dr Jean Diodati, the uncle of his friend Charles Diodati. From Geneva he returned to Paris, and so to England. He was home again in August 1639, having been absent in all fifteen or sixteen months.

Milton's Continental tour, and especially the Italian portion of it, remained one of the chief pleasures of his memory through all his subsequent life. Nor was it quite without fruits of a literary kind. Besides two of his Latin *Epistolæ Familiares*, one to the Florentine grammarian Buommattei, and the other to Lucas Holstenius, there have to be assigned to Milton's sixteen months on the Continent his three Latin epigrams *Ad Leonoram Romæ Canentem*, his Latin scazons *Ad Salsillum Poetam Romanum Ægrotantem*, his fine and valuable poem in Latin hexameters entitled *Mansus*, and his *Five Italian Sonnets, with a Canzone*, celebrating the charms of some Italian lady he had met in his travels.

One sad and marring memory did mingle itself with all that was otherwise so delightful in his Italian reminiscences. His bosom friend and companion from boyhood, the half Italian Charles Diodati, who had been to him as Jonathan to David, and into whose ear he had hoped to pour the whole narrative of what he had seen and done abroad, had died during his absence. He had died, in Blackfriars, London, in August 1638, not four months after Milton had gone away on his tour. The intelligence had not reached Milton till some months afterwards, probably not till his second stay in Florence; and, though he must have learnt some of the particulars from the youth's uncle in Geneva, he did not know them fully till his return to England. How profoundly they affected him appears from his *Epitaphium Damonis*, then written in memory of his dead friend. The importance of this poem in Milton's biography cannot be overrated. It is perhaps the noblest of all his Latin poems; and, though in the form of a pastoral, and even of a pastoral of the most artificial sort, it is unmistakably an outburst of the most passionate personal grief. In this respect *Lycidas*, artistically perfect though that poem is, cannot be compared with it; and it is only the fact that *Lycidas* is in English, while the *Epitaphium Damonis* is in Latin, that has led to the notion that Edward King of Christ's College was peculiarly and pre-eminently the friend of Milton in his youth and early manhood.

That Milton, now in his thirty-first year, had been girding himself for some greater achievement in poetry than any he had yet attempted, *Comus* not excepted, we should have known otherwise. What we should not have known, but for an incidental passage in the *Epitaphium Damonis*, is that, at the time of his return from Italy, he had chosen a subject for such a high literary effort of a new Miltonic sort. The passage is one in which, after referring to the hopes of Diodati's medical career as so suddenly cut short by his death, Milton speaks of himself as the survivor and of his own projects in *his* profession of literature. In translation, it may run thus:—

> "I have a theme of the Trojans cruising our southern headlands,
> Shaping to song, and the realm of Imogen daughter of Pandras,
> Brennus and Arviragh, dukes, and Bren's bold brother, Belinus,
> Then the Armorican settlers under the laws of the Britons,
> Ay, and the womb of Igraine fatally pregnant with Arthur,
> Uther's son, whom he got disguised in Gorlois' likeness,
> All by Merlin's craft. O then, if life shall be spared me,
> Thou shalt be hung, my pipe, far off on some dying old pine tree,

Much forgotten of me, or else your Latian music
Changed for the British war screech! What then? For one to do all things,
One to hope all things, fits not! Prize sufficiently ample
Mine, and distinction great (unheard of ever thereafter
Though I should be and inglorious all through the world of the *stranger*),
If but the yellow haired Ouse shall read me, the drinker of Alan,
Humber, which whirls as it flows, and Trent's whole valley of orchards,
Thames my own Thames, above all, and Tamar's western waters,
Tawny with orcs, and where the white waves swinge the far Orkneys

Interpreted prosaically, this means that Milton was meditating an epic of which King Arthur was to be the central figure, but which should include somehow the whole cycle of British and Arthurian legend, and that not only was this epic to be in English, but he had resolved that all his poetry for the future should be in the same tongue

Not long after Milton's return the house at Horton ceased to be the family home Christopher Milton and his wife went to reside at Reading, taking the old gentleman with them, while Milton himself preferred London He had first taken lodgings in St Bride's Churchyard, at the foot of Fleet Street, but, after a while, probably early in 1640, he removed to a "pretty garden house" of his own, at the end of an entry, in the part of Aldersgate Street which lies immediately on the city side of what is now Maidenhead Court His sister, whose first husband had died in 1631, had married a Mr Thomas Agar, his successor in the Crown Office, and it was arranged that her two sons by her first husband should be educated by their uncle John Phillips, the younger of them, only nine years old, had boarded with him in the St Bride's Churchyard lodgings, and, after the removal to Aldersgate Street, the other brother, Edward Phillips, only a year older, became his boarder also Gradually a few other boys, the sons of well-to-do personal friends, joined the two Phillipses, whether as boarders or for daily lessons, so that the house in Aldersgate Street became a small private school The drudgery of teaching seems always to have been liked by Milton What meanwhile of the great Arthurian epic? That project, we find, had been given up, and Milton's mind was roving among many other subjects, and balancing their capabilities How he wavered between Biblical subjects and heroic subjects from British history, and how many of each kind suggested themselves to him, one learns from a list in his own handwriting among the Milton MSS at Cambridge It contains jottings of no fewer than fifty three subjects from the Old Testament, eight from the Gospels, thirty three from British and English history before the Conquest, and five from Scottish history It is curious that all or most of them are headed or described as subjects for "tragedies," as if the epic form had now been abandoned for the dramatic It is more interesting still to observe which of the subjects fascinated Milton most Though several of them are sketched pretty fully, not one is sketched at such length and so particularly as *Paradise Lost* It is the first subject on the list, and there are four separate drafts of a possible tragedy under that title two of them merely enumerating the *dramatis personæ* but the last two indicating the plot and the division into acts Thus, in 1640, twenty seven years before *Paradise Lost* was given to the world, he had put down the name on paper, and had committed himself to the theme

To these poetic dreamings and schemings there was to be a long interruption The Scottish National Covenant had led to extraordinary results Not only were Charles and Laud checkmated in their design of converting the mild Episcopal system which King James had established in Scotland into a high Laudian prelacy; but, in a General Assembly held at Glasgow in the end of 1638, Episcopacy had been utterly abolished in Scotland, and the old Presbyterian system of Knox and Melville revived. To avenge this, and restore the Scottish bishops, Charles had marched to the Border with an English army, but, met there by the Covenanting army under General Alexander Leslie, he had not deemed it prudent to risk a battle, and had yielded to a negotiation conceding to the Scots all their demands This "First Bishops' War," as it came to be called, was begun and concluded while Milton was abroad About the time of his return, however, Charles had again broken with the Scots Milton had been watching the course of affairs since then with close and eager interest He had seen and partaken in the sympathetic stir in favour of the Scots which ran through the popular and Puritan mind of England He had welcomed the practical proof of this sympathy given in that English parliament of April 1640, called "The Short Parliament," which Charles, in his straits for supplies against the Scots, had reluctantly summoned at last, but was obliged to dismiss as unmanageable Charles had, nevertheless, with money raised somehow, entered on the "Second Bishops' War" This time the result was momentous indeed The Scots, not waiting to be attacked in their own country, took the aggressive, and invaded England In August 1640, after one small engagement with a portion of Charles's army, they were in possession of Newcastle and of all the northern English counties The English then had their opportunity A treaty with the Scots was begun, which the English Puritans, who regarded their presence in England as the very blessing they had been praying for, were in no haste to finish, and, on the 3d of November 1640, there met that parliament which was to be famous in English history, and in the history of the world as "The Long Parliament"

Of the first proceedings of this parliament, including the trial and execution of Strafford, the impeachment and imprisonment of Laud and others, and the break down of the system of Thorough by miscellaneous reforms and by guarantees for parliamentary liberty, Milton was only a spectator It was when the church question emerged distinctly as the question paramount, and there had arisen divisions on that question among those who had been practically unanimous in matters of civil reform, that he plunged in as an active adviser There were three parties on the church question There was a high church party, contending for Episcopacy by divine right, and for the maintenance of English Episcopacy very much as it was, there was a middle party, defending Episcopacy on grounds of usage and expediency, but desiring to see the powers of bishops greatly curtailed, and a limited Episcopacy, with councils of presbyters round each bishop, substituted for the existing high Episcopacy, and there was the root-and branch party, as it called itself, desiring the entire abolition of Episcopacy and the reconstruction of the English Church on something like the Scottish Presbyterian model Since the opening of the parliament there had been a storm of pamphlets crossing one another in the air from these three parties The chief manifesto of the high-church party was a pamphlet by Joseph Hall, bishop of Exeter, entitled *Humble Remonstrance to the High Court of Parliament* In answer to Hall, and in representation of the views of the root-and branch party, there had stepped forth, in March 1640–41, five leading Puritan parish ministers, the initials of whose names, clubbed together on the title page of their joint production, made the uncouth word "Smectymnuus" These were Stephen Marshall, Edmund Calamy, Thomas Young, Matthew Newcomen, and William Spurstow. The Thomas Young whose name comes in the middle was no other than the Scottish Thomas Young who had been Milton's domestic preceptor in Bread Street. Having returned from Hamburg in 1628, he had been appointed to the vicarage of Stowmarket in Suffolk, in which living he had remained ever since, with the reputation of being one of the most solid and learned Puritans among the English parish clergy. The famous Smectymnuan pamphlet in reply to Hall was mainly Young's. What is more interesting is that his old pupil Milton was secretly in partnership with him and his brother Smectymnuans. Milton's hand is discernible in a portion of the original Smectymnuan pamphlet, and he continued to aid the Smectymnuans in their subsequent rejoinders to Hall's defences of himself. It was more in Milton's way, however, to appear in print independently; and in May 1641, while the controversy between Hall and the Smectymnuans was going on, he put forth a pamphlet of his own. It was entitled *Of Reformation touching Church Discipline in England and the Causes that have hitherto hindered it*, and consisted of a review of English ecclesiastical history, with an appeal to his countrymen to resume that course of reformation which he considered to have been prematurely stopped in the preceding century, and to sweep away the last relics of papacy and prelacy. Among all the root and branch pamphlets of the time it stood out, and stands out still, as the most thorough-going and tremendous. It was followed by four others in rapid succession,—to wit, *Of Prelatical Episcopacy and whether it may be deduced from the Apostolical Times* (June 1641), *Animadversions upon the Remonstrant's Defence against Smectymnuus* (July 1641), *The Reason of Church Government urged against Prelaty* (February 1641–42), *Apology against a Pamphlet called a Modest Confutation of the Animadversions*, &c. (March 1641–42). The first of these was directed chiefly against that middle party which advocated a limited Episcopacy, with especial reply to the arguments of Archbishop Ussher, as the chief exponent of the views of that party. Two of the others, as the titles imply, belong to the Smectymnuan series, and were castigations of Bishop Hall. The greatest of the four and the most important of all Milton's anti-Episcopal pamphlets after the first, is that entitled *The Reason of Church Government*. It is there that Milton takes his readers into his confidence, speaking at length of himself and his motives in becoming a controversialist. Poetry, he declares, was his real vocation; it was with reluctance that he had resolved to "leave a calm and pleasing solitariness, fed with cheerful and confident thoughts, to embark in a troubled sea of noises and hoarse disputes"; but duty had left him no option. The great poem or poems he had been meditating could wait; and meanwhile, though in prose polemics he had the use only of his "left hand," that hand should be used with all its might in the cause of his country and of liberty.

The parliament had advanced in the root and branch direction so far as to have passed a bill for the exclusion of bishops from the House of Lords, and compelled the king's assent to that bill, when, in August 1642, the further struggle between Charles and his subjects took the form of civil war. All England was then divided into the Royalists, supporting the king, and the Parliamentarians, adhering to that majority of the Commons, with a minority of the Lords, which sat on as the parliament. While the first battles of the civil war were being fought with varying success, this parliament, less impeded than when it had been full, moved on more and more rapidly in the root and branch direction, till, by midsummer 1643, the abolition of Episcopacy had been decided and the question of the future non-prelatic constitution of the Church of England referred to a synod of divines, to meet at Westminster under parliamentary authority. Of Milton's life through those first months of the civil war little is known. He remained in his house in Aldersgate Street, teaching his nephews and other pupils; and the only scrap that came from his pen was the semi-jocose sonnet bearing the title *When the Assault was intended to the City*. In the summer of 1643, however, there was a great change in the Aldersgate Street household. About the end of May, as his nephew Edward Phillips remembered, Milton went away on a country journey, without saying whither or for what purpose; and, when he returned, about a month afterwards, it was with a young wife, and with some of her sisters and other relatives in her company. He had, in fact, been in the very headquarters of the king and the Royalist army in and round Oxford; and the bride he brought back with him was a Mary Powell, the eldest daughter of Richard Powell, Esq., of Forest Hill, near Oxford. She was the third of a family of eleven sons and daughters, of good standing, but in rather embarrassed circumstances, and was seventeen years and four months old, while Milton was in his thirty-fifth year. However the marriage came about, it was a most unfortunate event. The Powell family were strongly Royalist, and the girl herself seems to have been frivolous, unsuitable, and stupid. Hardly were the honeymoon festivities over in Aldersgate Street when, her sisters and other relatives having returned to Forest Hill and left her alone with her husband, she pined for home again and begged to be allowed to go back on a visit. Milton consented, on the understanding that the visit was to be a brief one. This seems to have been in July 1643. Soon, however, the intimation from Forest Hill was that he need not look ever to have his wife in his house again. The resolution seems to have been mainly the girl's own, abetted by her mother; but, as the king's cause was then prospering in the field, it is a fair conjecture that the whole of the Powell family had repented of their sudden connexion with so prominent a Parliamentarian and assailant of the Church of England as Milton. While his wife was away, his old father, who had been residing for three years with his younger and lawyer son at Reading, came to take up his quarters in Aldersgate Street.

Milton's conduct under the insult of his wife's desertion was most characteristic. Always fearless and speculative, he converted his own case into a public protest against the existing law and theory of marriage. *The Doctrine and Discipline of Divorce Restored, to the good of both Sexes*, was the title of a pamphlet put forth by him in August 1643, without his name, but with no effort at concealment, declaring the notion of a sacramental sanctity in the marriage relation to be a clerically invented superstition, and arguing that inherent incompatibility of character, or contrariety of mind, between two married persons, is a perfectly just reason for divorce. There was no reference to his own case, except by implication; but the boldness of the speculation roused attention and sent a shock through London. It was a time when the authors of heresies of this sort, or of any sort, ran considerable risks. The famous Westminster Assembly of Divines, called by the Long Parliament, had met on the appointed day, July 1, 1643; the Scots, in consenting to send an army into England to assist the parliament in their war with the king, had proposed, as one of the conditions, their Solemn League and Covenant, binding the two nations to endeavour after a uniformity of religion and of ecclesiastical discipline, with the extirpation of all "heresy, schism, and profaneness," as well as popery and prelacy; the Solemn League and Covenant had been enthusiastically accepted in England, and was being sworn to universally by the Parliamentarians, and one immediate effect was that four eminent Scottish divines and two Scottish lay commissioners were added to the Westminster Assembly and became leaders there Whether Milton s divorce tract was formally discussed in the Assembly during the first months of its sitting is unknown, but it is certain that the London clergy, including not a few members of the Assembly, were then talking about it privately with anger and execration That there might be no obstacle to a more public prosecution Milton threw off the anonymous in a second and much enlarged edition of the tract, in February 1643–44, dedicated openly to the parliament and the Assembly Then, for a month or two, during which the gossip about him and his monstrous doctrine was spreading more and more, he turned his attention to other subjects Among the questions in agitation in the general ferment of opinion brought about by the civil war was that of a reform of the national system of education and especially of the universities To this question Milton made a contribution in June 1644, in a small *Tract on Education*, in the form of a letter to Mr Samuel Hartlib a German then resident in London and interesting himself busily in all philanthropic projects and schemes of social reform In the very next month, however, July 1644, he returned to the divorce subject in a pamphlet addressed specially to the clergy and entitled *The Judgment of Martin Bucer concerning Divorce* The outcry against him then reached its height He was attacked in pamphlets, he was denounced in pulpits all through London and more than once in sermons before the two Houses of Parliament by prominent divines of the Westminster Assembly strenuous efforts were made to bring him within definite parliamentary censure In the cabal formed against him for this purpose a leading part was played at the instigation of the clergy, by the Stationers Company of London That company representing the publishers and booksellers of London had a plea of their own against him on the ground that his doctrine was not only immoral but had been put forth in an illegal manner His first divorce treatise though published immediately after the "Printing Ordinance of the parliament of June 14, 1643, requiring all publications to be licensed for press by one of the official censors, and to be registered in the books of the Stationers Company, had been issued without licence and without registration Complaint to this effect was made against Milton with some others liable to the same charge of contempt of the printing ordinance, in a petition of the Stationers to the House of Commons in August 1644 and the matter came before committee both in that House and in the Lords It is to this [illegible] nd [illegible] gs, [illegible] ton *for the Liberty of Unlicensed Printing to the Parliament of England* It appeared in the end of November 1644, deliberately unlicensed and unregistered as was proper on such an occasion, and was a remonstrance addressed to the parliament as if in an oration to them face to face, against their ordinance of June 1643 and the whole system of licensing and censorship of the press Nobly eulogistic of the parliament in other respects, it denounced their printing ordinance as utterly unworthy of them, and of the new era of English liberties which they were initiating and called for its repeal Though that effect did not follow, the pamphlet virtually accomplished its purpose The licensing system had received its death blow, and, though the Stationers returned to the charge in another complaint to the House of Lords, Milton s offence against the press ordinance was condoned He was still assailed in pamphlets, and found himself "in a world of disesteem , but he lived on through the winter of 1644–45 undisturbed in his house in Aldersgate Street To this period there belong, in the shape of verse, only his sonnets ix and x, the first to some anonymous lady, and the second "to the Lady Margaret Ley," with perhaps the Greek lines entitled *Philosophus ad Regem Quendam.* His divorce speculation, however, still occupied him; and in March 1644–45 he published simultaneously his *Tetrachordon, or Expositions upon the four chief places of Scripture which treat of Marriage*, and his *Colasterion, a Reply to a nameless Answer against the Doctrine and Discipline of Divorce* In these he replied to his chief recent assailants, lay and clerical, with merciless severity.

It was not merely Milton s intellectual eminence that had saved him from prosecution for his divorce heresy A new tendency of national opinion on the church question had operated in his favour, and in favour of all forms of free speculation There had occurred in the Westminster Assembly itself, and more largely throughout the general community, that split of English Puritanism into the two opposed varieties of Presbyterianism on the one hand and Independency or Congregationalism on the other which explains the whole subsequent history of the Puritan revolution Out of this theoretical discussion as to the constitution of the church there had grown the all important practical question of toleration The Presbyterians insisted that the whole population of England should necessarily belong to the one national Presbyterian Church, be compelled to attend its worship, and be subject to its discipline, while the Independents demanded that, if a Presbyterian Church should be set up as the national and state paid church, there should at least be liberty of dissent from it, and toleration for those that chose to form themselves into separate congregations Vehement within the Westminster Assembly itself, the controversy had attained wider dimensions out of doors, and had inwrought itself in a most remarkable manner with the conduct of the war Orthodox Presbyterian Calvinists were still the majority of the Puritan body, but, in the new atmosphere of liberty, there had sprung up, from secret and long suppressed seeds in the English mind, a wonderful variety of sects and denominations, mingling other elements with their Calvinism, or hardly Calvinistic at all,—most of them, it is true, fervidly Biblical and Christian after their different sorts, but not a few professing the most coolly inquisitive and sceptical spirit, and pushing their speculations to strange extremes of free-thinking These sects, growing more and more numerous in the large towns, had become especially powerful in the English Parliamentary army That army had, in fact, become a marching academy of advanced opinionists and theological debaters Now, as all the new Puritan sects, differing however much among themselves, saw their existence and the perpetuity of their tenets threatened by that system of ecclesiastical uniformity which the Presbyterians proposed to establish, they had, one and all, abjured Presbyterianism, and adopted the opposite principle of Independency, with its appended principle of toleration Hence an extraordinary conflict of policies among those who seemed to be all Parliamentarians, all united in fighting against the king The auxiliary Scottish army, which had come into England in January 1643-44, and had helped the English generals to beat the king in the great battle of Marston Moor in July 1644, thought that he had then been almost sufficiently beaten, and that the object of the Solemn League and Covenant would be best attained by bringing him to such terms as should secure an immediate Presbyterian settlement and the suppression of the Independents and sectaries. In this the chief English commanders, such as Essex and Manchester, agreed substantially with the Scots Cromwell, on the other hand, who was now the recognized head of the army Independents, did not think that the king had been sufficiently beaten, even for the general purposes of the war, and was resolved that the war should be pushed on to a point at which a Presbyterian settlement should be impossible without guarantees for liberty of conscience and a toleration of non Presbyterian sects Through the latter part of 1644, accordingly, Milton had been saved from the penalties which his Presbyterian opponents would have inflicted on him by this general championship of liberty of opinion by Cromwell and the army Independents Before the middle of 1645 he, with others who were on the black books of the Presbyterians as heretics, was safer still Though the parliament had voted, in January 1644–45, that the future national church of England should be on the Presbyterian system, Cromwell and the Independents had taken care to have the question of toleration left open, and, within the next month or two, by Cromwell's exertions, a completely new face was put upon the war by the removal of all the chief officers that had been in command hitherto, and the equipment of the New Model army, with Fairfax as its commander in chief and Cromwell himself as lieutenant general The Scots and the stricter English Presbyterians looked on malignantly while this army took the field, calling it an "Army of Sectaries," and almost hoping it would be beaten On June 14, 1645, however, there was fought the great battle of Naseby, utterly ruining the king at last, and leaving only relics of his forces here and there Milton's position then may be easily understood Though his first tendency on the church question had been to some form of a Presbyterian constitution for the church, he had parted utterly now from the Scots and Presbyterians, and become a partisan of Independency, having no dread of "sects and schisms," but regarding them rather as healthy signs in the English body politic He was, indeed, himself one of the most noted sectaries of the time, for in the lists of sects drawn out by contemporary Presbyterian writers special mention is made of one small sect who were known as *Miltonists* or *Divorcers*

So far as Milton was concerned personally, his interest in the divorce speculation came to an end in July or August 1645, when, by friendly interference, a reconciliation was effected between him and his wife The ruin of the king's cause at Naseby had suggested to the Powells that it might be as well for their daughter to go back to her husband after their two years of separation It was not, however, in the house in Aldersgate Street that she rejoined him, but in a larger house, which he had taken in the adjacent street called Barbican, for the accommodation of an increasing number of pupils

The house in Barbican was tenanted by Milton from about August 1645 to September or October 1647 Among his first occupations there must have been the revision of the proof sheets of the first edition of his collected poems It appeared as a tiny volume, copies of which are now very rare, with the title *Poems of Mr John Milton, both English and Latin, composed at several times* The title page gives the date 1645, but January 1645–46 seems to have been the exact month of the publication The appearance of the volume indicates that Milton may have been a little tired by this time of his notoriety as a prose polemic, and desirous of being recognized once more in his original character of literary man and poet But, whether because his pedagogic duties now engrossed him or for other reasons very few new pieces were added in the Barbican to those that the little volume had thus made public In English, there were only the four sonnets now numbered xi –xiv, the first two entitled "On the Detraction which followed upon my writing certain Treatises," the third "To Mr Henry Lawes on his Airs," and the fourth "To the Religious Memory of Mrs Catherine Thomson," together with the powerful anti Presbyterian invective or "tailed sonnet" entitled "On the New Forcers of Conscience under the Long Parliament", and in Latin there were only the ode *Ad Joannem Rousium*, the trifle called *Apologus de Rustico et Hero*, and one interesting *Familiar Epistle* addressed to his Florentine friend Carlo Dati Some family incidents of importance, however, appertain to this time of residence in Barbican Oxford having surrendered to Fairfax in June 1646, the whole of the Powell family had to seek refuge in London, and most of them found shelter in Milton's house His first child, a daughter named Anne, was born there on the 29th of July that year, on the 1st of January 1646–47 his father in law Mr Powell died there, leaving his affairs in confusion, and in the following March his own father died there, at the age of eighty four, and was buried in the adjacent church of St Giles, Cripplegate For the rest, the two years in Barbican are nearly blank in Milton's biography The great Revolution was still running its course For a time Charles's surrender of himself, in May 1646, to the auxiliary Scottish army rather than to Fairfax and Cromwell, and his residence with that Scottish army at Newcastle in negotiation with the Scots, had given the Presbyterians the advantage, but, after the Scots had evacuated England in January 1646–47, leaving Charles a captive with his English subjects, and especially after the English army had seized him at Holmby in June 1647 and undertaken the further management of the treaty with him, the advantage was all the other way It was a satisfaction to Milton, and perhaps still a protection for him, that the "Army of Independents and Sectaries" had come to be really the masters of England

From Barbican Milton removed, in September or October 1647, to a smaller house in that part of High Holborn which adjoins Lincoln's Inn Fields His Powell relatives had now left him, and he had reduced the number of his pupils, or perhaps kept only his two nephews But, though thus more at leisure, he did not yet resume his projected poem, but occupied himself rather with three works of scholarly labour which he had already for some time had on hand One was the compilation in English of a complete history of England, or rather of Great Britain, from the earliest times, another was the preparation in Latin of a complete system of divinity, drawn directly from the Bible, and the third was the collection of materials for a new Latin dictionary Milton had always a fondness for such labours of scholarship and compilation Of a poetical kind there is nothing to record, during his residence in High Holborn, but an experiment in psalm translation, in the shape of Psalms lxxx -lxxxviii done into service metre in April 1648, and the *Sonnet to Fairfax*, written in September of the same year —This last connects him again with the course of public affairs The king, having escaped from the custody of the army chiefs, and taken refuge in the Isle of Wight, had been committed to closer custody there, all negotiation between him and parliament had been declared at an end, and the result would probably have been his deposition, but for the consequences of a secret treaty he had contrived to make with the Scots By this treaty the Scots engaged to invade England in the king's behalf, rescue him from the English parliament and army, and restore him to his full royalty, while he engaged in return to ratify the Covenant, the Presbyterian system of church government, and all the other conclusions of the Westminster Assembly, throughout England, and to put down Independency and the sects Thus, in May 1648, began what is called the Second Civil War, consisting first of new risings of the Royalists in various parts of England, and then of a conjunction of these with a great invasion of England by a Royalist Scottish army, under the command of the duke of Hamilton. It was all over in August 1648, when the crushing defeat of the Scottish army by Cromwell in the three days' battle of Preston, and the simultaneous suppression of the English Royalist insurrection in the south east counties by Fairfax's siege and capture of Colchester, left Charles at the mercy of the victors.—Milton's *Sonnet to Fairfax* was a congratulation to that general in chief of the parliament on his success at Colchester, and attested the exultation of the writer over the triumph of the Parliamentary cause. His exultation continued through what followed. After one more dying effort of the parliament at negotiation with Charles, the army took the whole business on itself. The king was brought from the Isle of Wight; the parliament, manipulated by the army officers, and purged of all members likely to impede the army's purpose, was converted into an instrument for that purpose; a court of high justice was set up for the trial of Charles; and on January 30, 1648-49, he was brought to the scaffold in front of Whitehall. By that act England became a republic, governed, without King or House of Lords, by the persevering residue or "Rump" of the recent House of Commons, in conjunction with an executive council of state, composed of forty one members appointed annually by that House.

The first Englishman of mark out of parliament to attach himself openly to the new republic was John Milton. This he did by the publication of his pamphlet entitled *Tenure of Kings and Magistrates, proving that it is lawful, and hath been held so in all ages, for any who have the power, to call to account a Tyrant or wicked King, and, after due conviction, to depose and put him to death, if the ordinary Magistrate have neglected to do it*. It was out within a fortnight after the king's death, and was Milton's last performance in the house in High Holborn. The chiefs of the new republic could not but perceive the importance of securing the services of a man who had so opportunely and so powerfully spoken out in favour of their tremendous act, and who was otherwise so distinguished. In March 1648-49, accordingly, Milton was offered, and accepted, the secretaryship for foreign tongues to the council of state of the new Commonwealth. The salary was to be £288 a year, worth about £1000 a year now. To be near his new duties in attendance on the council, which held its daily sittings for the first few weeks in Derby House, close to Whitehall, but afterwards regularly in Whitehall itself, he removed at once to temporary lodgings at Charing Cross. In the very first meetings of council which Milton attended he must have made personal acquaintance with President Bradshaw, Fairfax, Cromwell himself, Sir Henry Vane, Whitlocke, Henry Marten, Hasilrig, Sir Gilbert Pickering, and the other chiefs of the council and the Commonwealth, if indeed he had not known some of them before. After a little while, for his greater convenience, official apartments were assigned him in Whitehall itself.

At the date of Milton's appointment to the secretaryship he was forty years of age. His special duty was the drafting of such letters as were sent by the council of state, or sometimes by the Rump Parliament, to foreign states and princes, with the examination and translation of letters in reply, and with personal conferences, when necessary, with the agents of foreign powers in London, and with envoys and ambassadors. As Latin was the language employed in the written diplomatic documents, his post came to be known indifferently as the secretaryship for foreign tongues or the Latin secretaryship. In that post, however, his duties, more particularly at first, were very light in comparison with those of his official colleague, Mr Walter Frost, the general secretary. Foreign powers held aloof from the English republic as much as they could; and, while Mr Frost had to be present in every meeting of the council, keeping the minutes, and conducting all the general correspondence, Milton's presence was required only when some piece of foreign business did turn up. Hence, from the first, his employment in very miscellaneous work. Especially, the council looked to him for everything in the nature of literary vigilance and literary help in the interests of the struggling Commonwealth. He was employed in the examination of suspected papers, and in interviews with their authors and printers; and he executed several great literary commissions expressly entrusted to him by the council. The first of these was his pamphlet entitled *Observations on Ormond's Articles of Peace with the Irish Rebels*. It was published in May 1649, and was in defence of the republic against a complication of Royalist intrigues and dangers in Ireland. A passage of remarkable interest in it is one of eloquent eulogy on Cromwell. More important still was the *Eikonoklastes* (which may be translated "Image Smasher"), published by Milton in October 1649, by way of counterblast to the famous *Eikon Basilike* ("Royal Image"), which had been in circulation in thousands of copies since the king's death, and had become a kind of Bible in all Royalist households, on the supposition that it had been written by the royal martyr himself. A third piece of work was of a more laborious nature. In the end of 1649 there appeared abroad, under the title of *Defensio Regia pro Carolo I*, a Latin vindication of the memory of Charles, with an attack on the English Commonwealth, intended for circulation on the Continent. As it had been written, at the instance of the exiled royal family, by Salmasius, or Claude de Saumaise, of Leyden, then of enormous celebrity over Europe as the greatest scholar of his age, it was regarded as a serious blow to the infant Commonwealth. To answer it was thought a task worthy of Milton, and he threw his whole strength into the performance through the year 1650, interrupting himself only by a new and enlarged edition of his *Eikonoklastes*. Not till April 1651 did the result appear; but then the success was prodigious. Milton's Latin *Pro Populo Anglicano Defensio*, as it was called, ran at once over the British Islands and the Continent, rousing acclamation everywhere, and received by scholars as an annihilation of the great Salmasius. Through the rest of 1651 the observation was that the two agencies which had co operated most visibly in raising the reputation of the Commonwealth abroad were Milton's books and Cromwell's battles.—These battles of Cromwell, in the service of the Commonwealth he had founded, had kept him absent from the council of state, of which he was still a member, since shortly after the beginning of Milton's secretaryship. For nearly a year he had been in Ireland, as lord lieutenant, reconquering that country after its long rebellion; and then, for another year, he had been in Scotland, crushing the Royalist commotion there round Charles II, and annexing Scotland to the English republic. The annexation was complete on the 3d of September 1651, when Cromwell, chasing Charles II and his army out of Scotland, came up with them at Worcester and gained his crowning victory. The Commonwealth then consisted of England, Ireland, and Scotland, and Cromwell was its supreme chief.—Through the eventful year 1651, it has been recently ascertained, Milton had added to the other duties of his secretaryship that of Government journalist. Through the whole of that year, if not from an earlier period, he acted as licenser and superintending editor of the *Mercurius Politicus*, a newspaper issued twice a week, of which Mr Marchamont Needham was the working editor and proprietor. Milton's hand is discernible in some of the leading articles.

About the end of 1651 Milton left his official rooms in

Whitehall for a house he had taken on the edge of St James's Park, in what was then called Petty France, Westminster, but is now York Street. The house existed till the other day, but has been pulled down. In Milton's time it was a villa-looking residence, with a garden, in a neighbourhood of villas and gardens. He had now more to do in the special work of his office, in consequence of the increase of correspondence with foreign powers. But he had for some time been in ailing health, and a dimness of eyesight which had been growing upon him gradually for ten years had been settling rapidly, since his labour over the answer to Salmasius, into total blindness. Actually, before or about May 1652, when he was but in his forty fourth year, his blindness was total, and he could go about only with some one to lead him. Hence a rearrangement of his secretarial duties. Such of these duties as he could perform at home, or by occasional visits to the Council Office near, he continued to perform; but much of the routine work was done for him by assistants, one of them a well known German named Weckherlin, under the superintendence of Mr John Thurloe, who had succeeded Mr Walter Frost in the general secretaryship. Precisely to this time of a lull in Milton's secretaryship on account of his ill health and blindness we have to refer his two great companion sonnets *To the Lord General Cromwell* and *To Sir Henry Vane the Younger*. To about the same time, or more precisely to the interval between May and September 1652, though the exact date is uncertain, we have to refer the death of his only son, who had been born in his official Whitehall apartments in the March of the preceding year, and the death also of his wife, just after she had given birth to his third daughter, Deborah. With the three children thus left him,—Anne, but six years old, Mary, not four, and the infant Deborah,—the blind widower lived on in his house in Petty France in such desolation as can be imagined. He had recovered sufficiently to resume his secretarial duties, and the total number of his dictated state letters for the single year 1652 is equal to that of all the state letters of his preceding term of secretaryship put together. To the same year there belong also three of his Latin *Familiar Epistles*. In December 1652 there was published *Joannis Philippi Angli Responsio ad Apologiam Anonymi Cujusdam Tenebrionis*, being a reply by Milton's younger nephew, John Phillips, but touched up by Milton himself, to one of several pamphlets that had appeared against Milton for his slaughter of Salmasius. The ablest and most scurrilous of these, which had just appeared anonymously at the Hague, with the title *Regii Sanguinis Clamor ad Cœlum adversus Parricidas Anglicanos* ("Cry of the Royal Blood to Heaven against the English Parricides"), Milton was reserving for his own attention at his leisure.

On the 20th of April 1653 there was Cromwell's great act of armed interference by which he turned out the small remnant of the Rump Parliament, dismissed their council of state, and assumed the government of England, Ireland, and Scotland into his own hands. For several months, indeed, he acted only as interim dictator, governing by a council of his officers, and waiting for the conclusions of that select body of advisers which he had called together from all parts of the country, and which the Royalists nicknamed "The Barebones Parliament." In December 1653, however, his formal sovereignty began under the name of the Protectorate, passing gradually into more than kingship. This change from government by the Rump and its council to government by a single military Lord Protector and his council was regarded by many as treason to the republican cause, and divided those who had hitherto been the united Commonwealth's men into the "Pure Republicans" represented by such men as Bradshaw and Vane, and the "Oliverians," adhering to the Protector. Milton, whose boundless admiration of Cromwell had shown itself already in his Irish tract of 1649 and in his recent sonnet, was recognized as one of the Oliverians. He remained in Oliver's service and was his Latin secretary through the whole of the Protectorate. For a while, indeed, his Latin letters to foreign states in Cromwell's name were but few,—Mr Thurloe, as general secretary, officiating as Oliver's right hand man in everything, with a Mr Philip Meadows under him, at a salary of £200 a year, as deputy for the blind Mr Milton in foreign correspondence and translations. The reason for this temporary exemption of Milton from routine duty may have been that he was then engaged on an answer, by commission from the late Government, to the already mentioned pamphlet from the Hague entitled *Regii Sanguinis Clamor*. Salmasius was now dead, and the Commonwealth was too stable to suffer from such attacks, but no Royalist pamphlet had appeared so able or so venomous as this in continuation of the Salmasian controversy. All the rather because it was in the main a libel on Milton himself did a reply from his pen seem necessary. It came out in May 1654, with the title *Joannis Miltoni Angli pro Populo Anglicano Defensio Secunda* ("Second Defence of John Milton, Englishman, for the People of England"). It is one of the most interesting of all Milton's writings. The author of the libel to which it replied was Dr Peter du Moulin the younger, a naturalized French Presbyterian minister, then moving about in English society, close to Milton; but, as that was a profound secret, and the work was universally attributed on the Continent to an Alexander Morus, a French minister of Scottish descent, then of much oratorical celebrity in Holland,—who had certainly managed the printing in consultation with the now deceased Salmasius, and had contributed some portion of the matter,—Milton had made this Morus the responsible person and the one object of his castigations. They were frightful enough. If Salmasius had been slaughtered in the former *Defensio*, Morus was murdered and gashed in this. His moral character was blasted by exposure of his antecedents, and he was blazoned abroad in Europe as a detected clerical blackguard. The terrific castigation of Morus, however, is but part of the *Defensio Secunda*. It contains passages of singular autobiographical and historical value, and includes laudatory sketches of such eminent Commonwealth's men as Bradshaw, Fairfax, Fleetwood, Lambert, and Overton, together with a long panegyric on Cromwell himself and his career, which remains to this day unapproached for elaboration and grandeur by any estimate of Cromwell from any later pen. From about the date of the publication of the *Defensio Secunda* to the beginning of 1655 the only specially literary relics of Milton's life are his translations of Psalms i.–viii. in different metres, done in August 1654, his translation of Horace's *Ode* i. 5, done probably about the same time, and two of his Latin *Familiar Epistles*. The most active time of his secretaryship for Oliver was from April 1655 onwards. In that month, in the course of a general revision of official salaries under the Protectorate, Milton's salary of £288 a year hitherto was reduced to £200 a year, with a kind of redefinition of his office, recognizing it, we may say, as a Latin secretaryship extraordinary. Mr Philip Meadows was to continue to do all the ordinary Foreign Office work, under Thurloe's inspection, but Milton was to be called in on special occasions. Hardly was the arrangement made when a signal occasion did occur. In May 1655 all England was horrified by the news of the massacre of the Vaudois Protestants by the troops of Emanuele II., duke of Savoy and prince of Piedmont, in consequence of their disobedience to an edict requiring them either to leave their native valleys or to conform to the Catholic religion Cromwell and his council took the matter up with all their energy, and the burst of indignant letters on the subject despatched in that month and the next to the duke of Savoy himself, Louis XIV of France, Cardinal Mazarin, the Swiss cantons, the States General of the United Provinces, and the kings of Sweden and Denmark, were all by Milton His famous sonnet *On the late Massacre in Piedmont* was his more private expression of feeling on the same occasion This sonnet was in circulation, and the case of the Vaudois Protestants was still occupying Cromwell, when, in August 1655, there appeared the last of Milton's great Latin pamphlets It was his *Pro Se Defensio*, in answer to an elaborate self defence which Morus had put forth on the Continent since Milton's attack on his character, and it consisted mainly of a re-exposure of that unfortunate clergyman Thence, through the rest of Cromwell's Protectorate, Milton's life was of comparatively calm tenor He was in much better health than usual, bearing his blindness with courage and cheerfulness, he was steadily busy with such more important despatches to foreign powers as the Protector, then in the height of his great foreign policy, and regarded with fear and deference by all European monarchs and states from Gibraltar to the Baltic, chose to confide to him, and his house in Petty France seems to have been, more than at any previous time since the beginning of his blindness, a meeting place for friends and visitors, and a scene of pleasant hospitalities The four sonnets now numbered xix–xxii, one of them to young Mr Lawrence, the son of the president of Cromwell's council, and two of the others to Cyriack Skinner, belong to this time of domestic quiet, as do also no fewer than ten of his Latin *Familiar Epistles* His second marriage belongs to the same years, and gleams even yet as the too brief consummation of this happiest time in the blind man's life The name of his second wife was Katharine Woodcock He married her on the 12th of November 1656 but, after only fifteen months, he was again a widower by her death in childbirth in February 1657–58 The child dying with her, only the three daughters by the first marriage remained The touching sonnet which closes the series of Milton's *Sonnets* is his sacred tribute to the memory on his second marriage and to the virtues of the wife he had so soon lost Even after that loss we find him still busy for Cromwell Mr Meadows having been sent off on diplomatic missions, Andrew Marvell had in September 1657, been brought in, much to Milton's satisfaction as his assistant or colleague in the Latin secretaryship but this had by no means relieved him from duty Some of his greatest despatches for Cromwell, including letters, of the highest importance, to Louis XIV, Mazarin, and Charles Gustavus of Sweden belong to the year 1658

One would like to know precisely in what personal relations Milton and Cromwell stood to each other There is, unfortunately, no direct record to show what Cromwell thought of Milton, but there is ample record of what Milton thought of Cromwell "Our chief of men,' he had called Cromwell in his sonnet of May 1652, and the opinion remained unchanged He thought Cromwell the greatest and best man of his generation, or of many generations, and he regarded Cromwell's assumption of the supreme power, and his retention of that power with a sovereign title, as no real suppression of the republic, but as absolutely necessary for the preservation of the republic, and for the safeguard of the British Islands against a return of the Stuarts Nevertheless, under this prodigious admiration of Cromwell, there were political doubts and reserves Milton was so much of a modern radical of the extreme school in his own political views and sympathies that he cannot but have been vexed by the growing conservatism of Cromwell's policy through his Protectorate To his grand panegyric on Oliver in the *Defensio Secunda* of 1654 he had ventured to append cautions against self will, over legislation, and over policing, and he cannot have thought that Oliver had been immaculate in these respects through the four subsequent years The attempt to revive an aristocracy and a House of Lords, on which Cromwell was latterly bent, cannot have been to Milton's taste Above all, Milton dissented *in toto* from Cromwell's church policy It was Milton's fixed idea, almost his deepest idea, that there should be no such thing as an Established Church, or state-paid clergy, of any sort or denomination or mixture of denominations, in any nation, and that, as it had been the connexion between church and state, begun by Constantine, that had vitiated Christianity in the world, and kept it vitiated, so Christianity would never flourish as it ought till there had been universal disestablishment and disendowment of the clergy, and the propagation of the gospel were left to the zeal of voluntary pastors, self supported, or supported modestly by their flocks He had at one time looked to Cromwell as the likeliest man to carry this great revolution in England But Cromwell, after much meditation on the subject in 1652 and 1653, had come to the opposite conclusion The conservation of the Established Church of England, in the form of a broad union of all evangelical denominations of Christians, whether Presbyterians, or Independents, or Baptists, or moderate Old Anglicans, that would accept state pay with state-control, had been the fundamental notion of his Protectorate, persevered in to the end This must have been Milton's deepest disappointment with the Oliverian rule

Cromwell's death on the 3d of September 1658 left the Protectorship to his son Richard Milton and Marvell continued in their posts, and a number of the Foreign Office letters of the new Protectorate were of Milton's composition Thinking the time fit, he also put forth, in October 1658, a new edition of his *Defensio Prima*, and, early in 1659, a new English pamphlet, entitled *Treatise of Civil Power in Ecclesiastical Causes*, ventilating those notions of his as to the separation of church and state which he had been obliged of late to keep to himself. To Richard's Protectorate also belongs one of Milton's Latin *Familiar Epistles* Meanwhile, though all had seemed quiet round Richard at first, the jealousies of the army officers left about him by Oliver, and the conflict of political elements let loose by Oliver's death, were preparing his downfall In May 1659 Richard's Protectorate was at an end The country had returned with pleasure to what was called "the good old cause" of pure republicanism, and the government was in the hands of "the Restored Rump," consisting of the reassembled remains of that Rump Parliament which Cromwell had dissolved in 1653 To this change, as inevitable in the circumstances, or even promising, Milton adjusted himself The last of his known official performances in his Latin secretaryship are two letters in the name of William Lenthall, as the speaker of the restored Rump, one to the king of Sweden and one to the king of Denmark, both dated May 15, 1659 Under the restored Rump, if ever, he seemed to have a chance for his notion of church-disestablishment, and, accordingly, in August 1659, he put forth, with a prefatory address to that body, a large pamphlet entitled *Considerations touching the likeliest means to remove Hirelings out of the Church* The restored Rump had no time to attend to such matters They were in struggle for their own existence with the army chiefs, and the British Islands were in that state of hopeless confusion and anarchy which, after passing through a brief phase of attempted military government (October to December 1659), and a second revival of the purely republican or Rump government (December 1659 to

February 1659–60), issued in Monk's march from Scotland, assumption of the dictatorship in London, and recall of all the survivors of the original Long Parliament to enlarge the Rump to due dimensions and assist him in further deliberations Through all this anarchy the Royalist elements had been mustering themselves, and the drift to the restoration of the Stuart dynasty, as the only possible or feasible conclusion, had become apparent To prevent that issue, to argue against it and fight against it to the last, was the work to which Milton had then set himself His disestablishment notion and all his other notions had been thrown aside, the preservation of the republic in any form, and by any compromise of differences within itself, had become his one thought, and the study of practical means to this end his most anxious occupation In a *Letter to a Friend concerning the Ruptures of the Commonwealth*, written in October 1659, he had propounded a scheme of a kind of dual government for reconciling the army chiefs with the Rump, through the following winter, marked only by two of his Latin *Familiar Epistles*, his anxiety over the signs of the growing enthusiasm throughout the country for the recall of Charles II had risen to a kind of agony, and early in March 1659–60 his agony found vent in a pamphlet of the most passionate vehemence entitled *The Ready and Easy Way to Establish a Free Commonwealth, and the Excellence thereof compared with the Inconveniences and Dangers of readmitting Kingship in this Nation* An abridgment of the practical substance of this pamphlet was addressed by him to General Monk in a letter entitled *The Present Means and Brief Delineation of a Free Commonwealth* Milton's proposal was that the central governing apparatus of the British Islands for the future should consist of one indissoluble Grand Council or parliament, which should include all the political chiefs, while there should be a large number of provincial councils or assemblies sitting in the great towns for the management of local and county affairs The scheme, so far as the public attended to it at all, was received with laughter the Royalist demonstrations were now fervid and tumultuous and it remained only for the new and full parliament of two Houses which had been summoned under Monk's auspices, and which is now known as the Convention Parliament, to give effect to Monk's secret determination and the universal popular desire Not even then would Milton be silent In *Brief Notes on a late Sermon*, published in April 1660, in reply to a Royalist discourse by a Dr Griffith, he made another protest against the recall of the Stuarts, even hinting that it would be better that Monk should become king himself, and in the same month he sent forth a second edition of his *Ready and Easy Way*, more frantically earnest than even the first, and containing additional passages of the most violent denunciation of the royal family, and of prophecy of the degradation and disaster they would bring back with them This was the dying effort On the 25th of April the Convention Parliament met, on the 1st of May they resolved unanimously that the government by King, Lords, and Commons should be restored, and on the 29th of May Charles II made his triumphal entry into London The chief republicans had by that time scattered themselves, and Milton was in hiding in an obscure part of the city

How Milton escaped the scaffold at the Restoration is a mystery now, and was a mystery at the time Actually, in the terrible course through the two Houses of the Convention Parliament of that Bill of Indemnity by which the fates of the surviving regicides and of so many others of the chief republican culprits were determined, Milton was named for special punishment It was voted by the Commons that he should be taken into custody by the sergeant-at-arms, for prosecution by the attorney-general on account of his *Eikonoklastes* and *Defensio Prima*, and that all copies of those books should be called in and burnt by the hangman There was, however, some powerful combination of friendly influences in his favour, with Monk probably abetting At all events, on the 29th of August 1660, when the Indemnity Bill did come out complete, with the king's assent, granting full pardon to all for their past offences, with the exception of about a hundred persons named in the bill itself for various degrees of punishment, thirty four of them for death and twenty-six for the highest penalty short of death, Milton did not appear as one of the exceptions on any ground or in any of the grades From that moment, therefore, he could emerge from his hiding, and go about as a free man Not that he was yet absolutely safe During the next two or three months London was in excitement over the trials of such of the excepted regicides and others as had not succeeded in escaping abroad, and the hangings and quarterings of ten of them, there were several public burnings by the hangman at the same time of Milton's condemned pamphlets, and the appearance of the blind man himself in the streets, though he was legally free, would have caused him to be mobbed and assaulted Nay, notwithstanding the Indemnity Bill, he was in some legal danger to as late as December 1660 Though the special prosecution ordered against him by the Commons had been quashed by the subsequent Indemnity Bill, the sergeant-at-arms had taken him into custody Entries in the Commons journals of December 17 and 19 show that Milton complained of the sergeant at arms for demanding exorbitant fees for his release, and that the House arranged the matter

Milton did not return to Petty France For the first months after he was free he lived as closely as possible in a house near what is now Red Lion Square, Holborn Thence he removed, apparently early in 1661, to a house in Jewin Street, in his old Aldersgate Street and Barbican neighbourhood

In Jewin Street Milton remained for two or three years, or from 1661 to 1664 They were the time of his deepest degradation, that time of which he speaks when he tells us how, by the Divine help, he had been able to persevere undauntedly—

> ' though fallen on evil days,
> On evil days though fallen and evil tongues,
> In darkness and with dangers compassed round,
> [illegible]

The "evil days" were those of the Restoration in its first or Clarendonian stage, with its revenges and reactions, its return to high Episcopacy and suppression of every form of dissent and sectarianism, its new and shameless royal court, its open proclamation and practice of anti Puritanism in morals and in literature no less than in politics For the main part of this world of the Restoration Milton was now nothing more than an infamous outcast, the detestable blind republican and regicide who had, by too great clemency, been left unhanged The friends that adhered to him still, and came to see him in Jewin Street, were few in number, and chiefly from the ranks of those nonconforming denominations, Independents, Baptists, or Quakers, who were themselves under similar obloquy Besides his two nephews, the faithful Andrew Marvell, Cyriack Skinner, and some others of his former admirers, English or foreign, we hear chiefly of a Dr Nathan Paget, who was a physician in the Jewin Street neighbourhood, and of several young men who would drop in upon him by turns, partly to act as his amanuenses, and partly for the benefit of lessons from him,—one of them an interesting Quaker youth, named Thomas Ellwood With all this genuine attachment to him of a select few, Milton could truly enough describe his condition after the Restoration as one of "solitude" Nor was this the worst His three daughters, on whom he ought now to have been able principally to depend, were his most serious domestic trouble The poor motherless girls, the eldest in her seventeenth year in 1662, the second in her fifteenth, and the youngest in her eleventh, had grown up, in their father's blindness and too great self absorption, ill looked-after and but poorly educated, and the result now appeared They "made nothing of neglecting him", they rebelled against the drudgery of reading to him or otherwise attending on him, they "did combine together and counsel his maid servant to cheat him in her marketings", they actually "had made away some of his books, and would have sold the rest" It was to remedy this horrible state of things that Milton consented to a third marriage The wife found for him was Elizabeth Minshull, of a good Cheshire family, and a relative of Dr Paget's They were married on the 24th of February 1662–63, the wife being then only in her twenty fifth year, while Milton was in his fifty fifth She proved an excellent wife, and the Jewin Street household, though the daughters remained in it, must have been under better management from the time of her entry into it From that date Milton's circumstances must have been more comfortable, and his thoughts about himself less abject, than they had been through the two preceding years, though his feeling in the main must have been still that of his own Samson —

"Now blind disheartened shamed, dishonoured, quelled,
To what can I be useful? wherein serve
My nation, and the work from heaven imposed?
But to sit idle on the household hearth,
A burdenous drone, to visitants a gaze,
Or pitied object

That might be the appearance, but it was not the reality All the while of his seeming degradation he had found some solace in renewed industry of various kinds among his books and tasks of scholarship, and all the while, more particularly, he had been building up his *Paradise Lost* He had begun the poem in earnest, we are told, in his house in Petty France, in the last year of Cromwell's Protectorate, and then not in the dramatic form contemplated eighteen years before, but deliberately in the epic form He had made but little way when there came the interruption of the anarchy preceding the Restoration and of the Restoration itself, but the work had been resumed in Jewin Street and prosecuted there steadily, by dictations of twenty or thirty lines at a time to whatever friendly or hired amanuensis chanced to be at hand Considerable progress had been made in this way before his third marriage, and after that the work proceeded apace, his nephew Edward Phillips, who was then out in the world on his own account, looking in when he could to revise the growing manuscript

It was not in the house in Jewin Street, however, that *Paradise Lost* was finished Not very long after the third marriage, probably in 1664, there was a removal to another house, with a garden, not far from Jewin Street, but in a more private portion of the same suburb This, which was to be the last of all Milton's London residences, was in the part of the present Bunhill Row which faces the houses that conceal the London artillery ground and was then known as "Artillery Walk, leading to Bunhill Fields" Here the poem was certainly finished before July 1665, for, when, in that month, Milton and his family, to avoid the Great Plague of London, then beginning its fearful ravages, went into temporary country quarters in a cottage in Chalfont St Giles, Buckinghamshire, about 23 miles from London, the finished manuscript was taken with him, in probably more than one copy This we learn from his young Quaker friend, Thomas Ellwood, who had taken the cottage for him, and who was shown one of the manuscript copies, and allowed to take it away with him for perusal, during Milton's stay at Chalfont. Why the poem was not published immediately after his return to his Bunhill house in London, on the cessation of the Great Plague, does not distinctly appear, but may be explained partly by the fact that the official licenser hesitated before granting the necessary *imprimatur* to a book by a man of such notorious republican antecedents, and partly by the paralysis of all business in London by the Great Fire of September 1666 It was not till the 27th of April 1667 that Milton concluded an agreement with a publisher for the printing of his epic By the agreement of that date, still extant, Milton sold to Samuel Simmons, printer, of Aldersgate Street, London, for £5 down, the promise of another £5 after the sale of a first edition of thirteen hundred copies, and the further promise of two additional sums of £5 each after the sale of two more editions of the same size respectively, all his copyright and commercial interest in *Paradise Lost* for ever It was as if an author now were to part with all his rights in a volume for £17, 10s down, and a contingency of £52, 10s more in three equal instalments The poem was duly entered by Simmons as ready for publication in the Stationers' Registers on the 20th of the following August, and shortly after that date it was out in London as a neatly printed small quarto, with the title *Paradise Lost A Poem written in Ten Books By John Milton* The publishing price was 3s, equal to about 10s. 6d now It is worth noting as an historical coincidence that the poem appeared just at the time of the fall and disgrace of Clarendon

The effect of the publication of *Paradise Lost* upon Milton's reputation can only be described adequately, as indeed it was consciously described by himself in metaphor, by his own words on Samson's feat of triumph over the Philistines —

But he, though blind of sight,
Despised, and thought extinguished quite
With inward eyes illuminated,
His fiery virtue roused
From under ashes into sudden flame,
And as an evening dragon came,
Assailant on the perched roosts
And nests in order ranged
Of tame villatic fowl but as an eagle
His cloudless thunder bolted on their heads"

As the poem circulated and found readers, whether in the first copies sent forth by Simmons, or in subsequent copies issued between 1667 and 1669, with varied title pages, and the latest of them with a prefixed prose "Argument," the astonishment broke out everywhere "This man cuts us all out, and the ancients too" is the saying attributed to Dryden on the occasion, and it is the more remarkable because the one objection to the poem which at first, we are told, "stumbled many" must have "stumbled" Dryden most of all Except in the drama, rhyme was then thought essential in anything professing to be a poem, blank verse was hardly regarded as verse at all, Dryden especially had been and was the champion of rhyme, contending for it even in the drama, and yet here was an epic not only written in blank verse, but declaring itself on that account to be "an example set, the first in English, of ancient liberty recovered to heroic poem from the troublesome and modern bondage of riming" That, notwithstanding this obvious blow struck by the poem at Dryden's pet literary theory, he should have welcomed the poem so enthusiastically and proclaimed its merits so emphatically, says much at once for his critical perception and for the generosity of his temper An opinion proclaimed by the very chief of the Restoration literature could not but prevail among the contemporary scholars, and, though execration of the blind and unhanged regicide had not ceased among the meaner critics, the general vote was that he had nobly redeemed himself One consequence of his renewed celebrity was that visitors of all ranks again sought him out for the honour of his society and conversation His obscure house in Artillery Walk, Bunhill, we are told, became an attraction now, "much more than he did desire, for the learned notabilities of his time

The year 1669, when the first edition of *Paradise Lost* had been completely sold out, and Milton had received his second £5 on account of it, may be taken as the time of the perfect recognition of his pre eminence among the English poets of his generation He was then sixty years of age, and it is to about that year that the accounts that have come down to us of his personal appearance and habits in his later life principally refer They describe him as to be seen every other day led about in the streets in the vicinity of his Bunhill residence, a slender figure, of middle stature or a little less, generally dressed in a grey cloak or overcoat, and wearing sometimes a small silver hilted sword, evidently in feeble health, but still looking younger than he was, with his lightish hair, and his fair, rather than aged or pale, complexion He would sit in his garden at the door of his house, in warm weather, in the same kind of grey overcoat, "and so, as well as in his room, received the visits of people of distinguished parts, as well as quality' Within doors he was usually dressed in neat black He was a very early riser, and very regular in the distribution of his day, spending the first part, to his midday dinner, always in his own room, amid his books with an amanuensis to read for him and write to his dictation Music was always a chief part of his afternoon and evening relaxation, whether when he was by himself or when friends were with him His manner with friends and visitors was extremely courteous and affable, with just a shade of stateliness In free conversation, either at the midday dinner, when a friend or two happened, by rare accident, to be present, or more habitually in the evening and at the light supper which concluded it, he was the life and soul of the company, from his "flow of subject and his "unaffected cheerfulness and civility, though with a marked tendency to the satirical and sarcastic in his criticisms of men and things This tendency to the sarcastic was connected by some of those who observed it with a peculiarity of his voice or pronunciation "He pronounced the letter *r* very hard Aubrey tells us, adding Dryden s note on the subject "*litera canina*, the dog letter, a certain sign of a satirical wit He was extremely temperate in the use of wine or any strong liquors, at meals and at all other times, and when supper was over, about nine o clock, "he smoked his pipe and drank a glass of water, and went to bed He suffered much from gout, the effects of which had become apparent in a stiffening of his hands and finger joints, and the recurring attacks of which in its acute form were very painful His favourite poets among the Greeks were Homer and the Tragedians, especially Euripides, among the Latins, Virgil and Ovid, among the English, Spenser and Shakespeare Among his English contemporaries, he thought most highly of Cowley He had ceased to attend any church, belonged to no religious communion, and had no religious observances in his family His reasons for this were a matter for curious surmise among his friends, because of the profoundly religious character of his own mind, but he does not seem ever to have furnished the explanation The matter became of less interest perhaps after 1669, when his three daughters ceased to reside with him, having been sent out, at considerable expense, "to learn some curious and ingenious sorts of manufacture that are proper for women to learn, particularly embroideries in gold or silver" After that the household in Bunhill consisted only of Milton, his wife, a single maid servant, and the "man or amanuensis who came in for the day

The remaining years of Milton s life, extending through that part of the reign of Charles II which figures in English history under the name of "The Cabal Administration,' were by no means unproductive In 1669 he published, under the title of *Accedence Commenced Grammar*, a small English compendium of Latin grammar that had been lying among his papers In 1670 there appeared, in a rather handsome form and with a prefixed portrait of him by Faithorne, done from the life and the best and most authentic that now exists, his *History of Britain to the Norman Conquest*, being all that he had been able to accomplish of his intended complete history of England In 1671 there followed his *Paradise Regained* and *Samson Agonistes*, bound together in one small volume, and giving ample proof that his poetic genius had not exhausted itself in the preceding great epic His only publication in 1672 was a Latin digest of Ramist logic, entitled *Artis Logicæ Plenior Institutio*, of no great value, and doubtless from an old manuscript of his earlier days In 1673, at a moment when the growing political discontent with the government of Charles II and the conduct of his court had burst forth in the special form of a "No-Popery" agitation and outcry, Milton ventured on the dangerous experiment of one more political pamphlet, in which, under the title *Of True Religion, Heresy, Schism, Toleration, and what best means may be used against the growth of Popery*, he put forth, with a view to popular acceptance, as mild a version as possible of his former principles on the topics discussed In the same year appeared the second edition of his *Minor Poems* Thus we reach the year 1674, the last of Milton s life One incident of that year was the publication of the second edition of *Paradise Lost*, with the poem rearranged as now into twelve books, instead of the original ten Another was the publication of a small volume containing his Latin *Epistolæ Familiares*, together with the *Prolusiones Oratoriæ* of his student days at Cambridge,—these last thrown in as a substitute for his Latin state letters in his secretaryship for the Commonwealth and the Protectorate, the printing of which was stopped by order from the Foreign Office A third publication of the same year, and probably the very last thing dictated by Milton, was a translation of a Latin document from Poland relating to the recent election of the heroic John Sobieski to the throne of that kingdom, with the title *A Declaration or Letters Patents of the Election of this present King of Poland, John the Third* It seems to have been out in London in August or September 1674 On the 8th of the following November, being a Sunday Milton died, in his house in Bunhill, of "gout struck in, or gout fever, at the age of sixty five years and eleven months He was buried, the next Thursday, in the church of St Giles, Cripplegate, beside his father, a considerable concourse attending the funeral

Before the Restoration Milton what with his inheritance from his father what with the official income of his Latin secretaryship, must have been a man of very good means indeed Since then, however, various heavy losses and the cessation of all official income, had greatly reduced his estate so that he left but £900 (worth about or over £2700 now) besides furniture and household goods By a word of mouth will made in presence of his brother Christopher, he had bequeathed the whole to his widow on the ground that he had done enough already for his ' undutiful daughters and that there remained for them his interest in their mother s marriage portion of £1000 which had never been paid but which their relatives, the Powells of Forest Hill, were legally bound for, and were now in circumstances to make good The daughters with the Powells probably abetting them went to law with the widow to upset the will, and the decision of the court was that they should receive £100 each With the £600 thus left, the widow, after some further stay in London, retired to Nantwich in her native Cheshire. There, respected as a pious member of a local Baptist congregation, she lived till 1727, having survived her husband fifty-three years. By that time all the three daughters were also dead. The eldest, Ann Milton, who was somewhat deformed, had died not long after her father, having married "a master-builder," but left no issue; the second, Mary Milton, had died, unmarried, before 1694; and only the third, Deborah, survived as long as her step-mother. Having gone to Ireland, as companion to a lady, shortly before her father's death, she had married an Abraham Clarke, a silk-weaver in Dublin, with whom she returned to London about 1684, when they settled in the silk-weaving business in Spitalfields, rather sinking than rising in the world, though latterly some public attention was paid to Deborah, by Addison and others, on her father's account. One of her sons, Caleb Clarke, had gone out to Madras in 1703, and had died there as "parish clerk of Fort George" in 1719, leaving children, of whom there are some faint traces to as late as 1727, the year of Deborah's death. Except for the possibility of further and untraced descent from this Indian grandson of Milton, the direct descent from him came to an end in his granddaughter Elizabeth Clarke, another of Deborah's children. Having married a Thomas Foster, a Spitalfields weaver, but afterwards set up a small chandler's shop, first in Holloway and then in Shoreditch, she died at Islington in 1754, not long after she and her husband had received the proceeds of a performance of *Comus* got up by Dr Johnson for her benefit. All her children had predeceased her, leaving no issue.—Milton's brother Christopher, who had always been on the opposite side in politics, rose to the questionable honour of a judgeship and knighthood in the latter part of the reign of James II. He had then become a Roman Catholic,—which religion he professed till his death in retirement at Ipswich in 1692. Descendants from him are traceable a good way into the 18th century.—Milton's two nephews and pupils, Edward and John Phillips, both of them known as busy and clever hack authors before their uncle's death, continued the career of hack authorship most industriously and variously, though not very prosperously, through the rest of their lives, Edward in a more reputable manner than John, and with more of enduring allegiance to the memory of his uncle. Edward died about 1696; John was alive till 1706. Their half-sister, Ann Agar, the only daughter of Milton's sister by her second husband, had married, in 1673, a David Moore, of Sayes House, Chertsey; and it has so happened that the most flourishing of all the lines of descent from the poet's father is in this Agar-Moore branch of the Miltons.

Of masses of manuscript that had been left by Milton, some portions saw the light posthumously. Prevented in the last year of his life, as has been mentioned, from publishing his Latin *State Letters* in the same volume with his Latin *Familiar Epistles*, he had committed the charge of the *State Letters*, prepared for the press, together with the completed manuscript of his Latin *Treatise of Christian Doctrine*, to a young Cambridge scholar, Daniel Skinner, who had been among the last of his amanuenses, and had, in fact, been employed by him specially in copying out and arranging those two important MSS. Negotiations were on foot, after Milton's death, between this Daniel Skinner and the Amsterdam printer, Daniel Elzevir, for the publication of both MSS., when the English Government interfered, and the MSS. were sent back by Elzevir, and thrown aside, as dangerous rubbish, in a cupboard in the State Paper Office. Meanwhile, in 1676, a London bookseller, named Pitt, who had somehow got into his possession a less perfect, but still tolerably complete, copy of the *State Letters*, had brought out a surreptitious edition of them under the title *Literæ Pseudo-Senatus Anglicani, necnon Cromwellii, nomine et jussu conscriptæ*. No other posthumous publication of Milton's appeared till 1681, when another bookseller put forth a slight tract entitled *Mr John Milton's Character of the Long Parliament and Assembly of Divines*, consisting of a page or two, of rather dubious authenticity, said to have been withheld from his *History of Britain* in the edition of 1670. In 1682 appeared *A Brief History of Moscovia and of other less-known Countries lying eastward of Russia as far as Cathay*, undoubtedly Milton's, and a specimen of those prose compilations with which he sometimes occupied his leisure. Of the fate of his collections for a new Latin *Dictionary*, which had swelled to three folio volumes of MS., all that is known is that, after having been used by Edward Phillips for some of *his* pedagogic books, they came into the hands of a committee of Cambridge scholars, and were used for that Latin dictionary of 1693 called *The Cambridge Dictionary*, on which Ainsworth's *Dictionary* and all subsequent Latin dictionaries of English manufacture have been based. In 1698 there was published in three folio volumes, under the editorship of John Toland, the first collective edition of Milton's prose works, professing to have been printed at Amsterdam, though really printed in London. A very interesting folio volume published in 1743 by "John Nickolls, junior," under the title of *Original Letters and Papers of State addressed to Oliver Cromwell*, consists of a number of intimate Cromwellian documents that had somehow come into Milton's possession immediately after Cromwell's death, and were left by him confidentially to the Quaker Ellwood. Finally, a chance search in the London State Paper Office in 1823 having discovered the long-lost parcel containing the MSS. of Milton's Latin *State Letters* and his Latin *Treatise of Christian Doctrine*, as these had been sent back from Amsterdam a hundred and fifty years before, the *Treatise on Christian Doctrine* was, by the command of George IV., edited and published in 1825 by the Rev. C. R. Sumner, keeper of the Royal Library, and afterwards bishop of Winchester, under the title of *Joannis Miltoni Angli De Doctrina Christiana Libri Duo Posthumi*. An English translation, by the editor, was published in the same year.

Information, rather than criticism, has seemed proper in such an article as the present. What little of closing remark is necessary will best connect itself with the obvious fact of the division of Milton's literary life into three almost mechanically distinct periods, viz.—(1) the time of his youth and minor poems, (2) his middle twenty years of prose polemics, and (3) the time of his later Muse and greater poems.

Had Milton died in 1640, when he was in his thirty-second year, and had his literary remains been then collected, he would have been remembered as one of the best Latinists of his generation and one of the most exquisite of minor English poets. In the latter character, more particularly, he would have taken his place as one of that interesting group or series of English poets coming in the next forty years after Spenser, who, because they all acknowledged a filial relationship to Spenser, may be called collectively The Spenserians. In this group or series, counting in it such other true poets of the reigns of James I. and Charles I. as Phineas and Giles Fletcher, William Browne, and Drummond of Hawthornden, Milton would have been entitled, by the small collection of pieces he had left, and which would have included his *Ode on the Nativity*, his *L'Allegro* and *Il Penseroso*, his *Comus*, and his *Lycidas*, to recognition as indubitably the very highest and finest. There was in him that peculiar Spenserian something which might be regarded as the poetic faculty in its essence, with a closeness and perfection of verbal finish not to be found in the other Spenserians, or even in the master himself. A very discerning critic might have gone deeper, as we can now. Few as the pieces were, and owning discipleship to Spenser as the author did, he was a Spenserian with a difference belonging to his own constitution,—which prophesied, and indeed already exhibited, the passage of English poetry out of the Spenserian into a kind that might be called the Miltonic. This Miltonic something, distinguishing the new poet from other Spenserians, was more than mere perfection of literary finish. It consisted in an avowed consciousness already of the *os magna sonaturum*, "the mouth formed for great utterances," that consciousness resting on a peculiar substratum of personal character that had occasioned a new theory of literature. "He who would not be frustrate of his hope to write well hereafter on laudable things ought himself to be a true poem," was Milton's own memorable expression afterwards of the principle that had taken possession of him from his earliest days; and this principle of moral manliness as the true foundation of high literary effort, of the inextricable identity of all literary productions in kind, and their coequality in worth, with the personality in which they have their origin, might have been detected, in more or less definite shape, in all or most of the minor poems. It is a specific form of that general Platonic doctrine of the invincibility of virtue which runs through his *Comus*, and which is summed up in the Miltonic motto of the closing lines:—

"Mortals, that would follow me,
Love Virtue; she alone is free:
She can teach ye how to climb
Higher than the sphery chime;
Or, if Virtue feeble were,
Heaven itself would stoop to her."

That a youth and early manhood of such poetical promise should have been succeeded by twenty years of all but incessant prose polemics has been a matter of regret with many. Why should the author of *Comus* and *Lycidas*, instead of keeping to the poetic craft, have employed himself for twenty years in the drudgery and turmoil of prose pamphleteering on questions of church and state, with nothing in verse to glitter across the long morass but a slight chain of biographical and historical sonnets? Surely this is a most shallow and most unmasculine judgment. Is nothing due to Milton's own explanation of the reasons that drew him, at the beginning of the English Revolution, out of his literary projects and dreamings, into active partisanship with the cause which his reason favoured? Hear what he says would have been the reproach of his own conscience to him, evening and morning, if he had abstained from such partisanship and persisted in his poetic privacy:—"Ease and leisure was given thee for thy retired thoughts out of the sweat of other men. Thou hadst the diligence, the parts, the language of a man, if a vain subject were to be adorned or beautified, but, when the cause of God and His church was to be pleaded, for which purpose that tongue was given thee which thou hast, God listened if He could hear thy voice among His zealous servants, but thou wert dumb as a beast: from henceforward be that which thine own brutish silence hath made thee." Or, if this should be in too high a strain for the ordinary modern apprehension, may not one ask, more simply, whether such controversial work as Milton did plunge into, and persevere in for twenty years, was unworthy, after all, of him or his powers? Do not hundreds of men, accounted among the ablest in the world, spend their lives precisely in such work of controversy on contemporary questions, and are not some of the men of noblest reputation in the world's history remembered for nothing else? If Burke, whose whole public career consisted in a succession of speeches and pamphlets, is looked back upon as one of the greatest men of his century on their account, why should there be such regret over the fact that Milton, after having been the author of *Comus* and *Lycidas*, became for a time the prose orator of *his* earlier and more tumultuous generation? The truth is that it is not his exchange of poetry for prose oratory that is objected to, so much as the nature of his prose oratory, the side he took, the opinions he advocated. English scholarship and English literary criticism have not yet sufficiently recovered from that inherited sycophancy to the Restoration which has covered with a cloud the preceding twenty years of the "Great Rebellion," voting that period of English history to be unrespectable, and all its phenomena of Presbyterianism, the Solemn League and Covenant, Independency, the sects, English republicanism, &c., to be matters of obsolete jargon, less worthy of attention than a Roman agrarian law or the names of Horace's mistresses. When this unscholarly state of temper has passed, there will be less disposition to distinguish between Milton as the poet and Milton as the prose writer. While some may recognize, with the avidity of assent and partisanship, the fact that there are in Milton's prose writings notions of much value and consequence that have not yet been absorbed into the English political mind, there will be a general agreement at least as to the importance of those pamphlets historically. It will be perceived that he was not only the greatest pamphleteer of his generation, head and shoulders above the rest, but also that there is no life of that time, not even Cromwell's, in which the history of the great Revolution in its successive phases, so far as the deep underlying ideas and speculations were concerned, may be more intimately and instructively studied than in Milton's. Then on merely literary grounds, what an interest in those prose remains! Not only of his *Areopagitica*, admired now so unreservedly because its main doctrine has become axiomatic, but of most of his other pamphlets, even those the doctrine of which is least popular, it may be said confidently that they answer to his own definition of "a good book," by containing somehow "the precious life blood of a master-spirit." From the entire series there might be a collection of specimens unequalled anywhere else, of the capabilities of that older, grander and more elaborate English prose of which the Elizabethans and their immediate successors were not ashamed, though it has fallen into disrepute now in comparison with the easier and nimbler prose which came in with Dryden. Nor will readers of Milton's pamphlets continue to accept the hackneyed observation that his genius was destitute of humour. Though his prevailing mood was the severely earnest, there are pages in his prose writings, both English and Latin, of the most laughable irony, reaching sometimes to outrageous farce, and some of them as worthy of the name of humour as anything in Swift. Here, however, we touch on what is the worst feature in some of the prose pamphlets,—their measureless ferocity, their boundless licence in personal scurrility. With all allowance for the old custom of those days, when controversy was far more of a life and death business than it is now, as well as for the intrinsic soundness of Milton's rule of always discerning the *man* behind the *book*, it is impossible for the most tolerant of modern readers to excuse Milton in this respect to the full extent of his delinquencies.

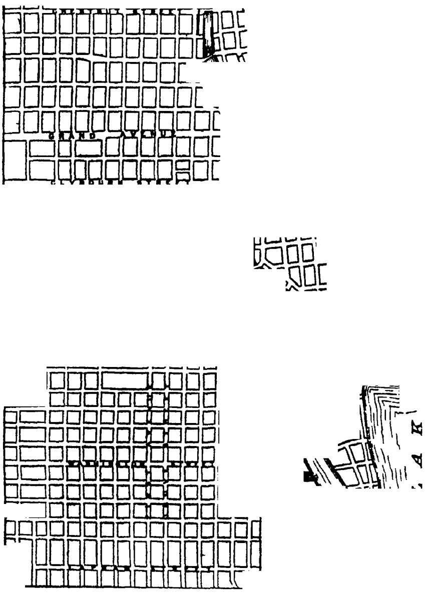
While it is wrong to regard Milton's middle twenty years of prose polemics as a degradation of his genius, and while the fairer contention might be that the youthful poet of *Comus* and *Lycidas* actually promoted himself, and became a more powerful agency in the world and a more interesting object in it for ever, by consenting to lay aside his "singing robes" and spend a portion of his life in great prose oratory, who does not exult in the fact that such a life was rounded off so miraculously at the close by a final stage of compulsory calm, when the "singing robes" could be resumed, and *Paradise Lost*, *Paradise Regained*, and *Samson Agonistes* could issue in succession from the blind man's chamber? Of these three poems, and what they reveal of Milton, no need here to speak at length. *Paradise Lost* is one of the few monumental works of the world, with nothing in modern epic literature comparable to it except the great poem of Dante. This is best perceived by those who penetrate beneath the beauties of the merely terrestrial portion of the story, and who recognize the coherence and the splendour of that vast symbolic phantasmagory by which, through the wars in heaven and the subsequent revenge of the expelled archangel, it paints forth the connexion of the whole visible universe of human cognizance and history with the grander, pre-existing, and still environing world of the eternal and inconceivable. To this great epic *Paradise Regained* is a sequel, and it ought to be read as such. The legend that Milton preferred the shorter epic to the larger is quite incorrect. All that is authentic on the subject is the statement by Edward Phillips that, when it was reported to his uncle that the shorter epic was "generally censured to be much inferior to the other," he "could not hear with patience any such thing." The best critical judgment now confirms Milton's own, and pronounces *Paradise Regained* to be not only, within the possibilities of its briefer theme, a worthy sequel to *Paradise Lost*, but also one of the most edifying and artistically perfect poems in any language. Finally, the poem in which Milton bade farewell to the Muse, and in which he reverted to the dramatic form, proves that to the very end his right hand had lost none of its power or cunning. *Samson Agonistes* is the most powerful drama in our language after the severe Greek model, and it has the additional interest of being so contrived that, without strain at any one point, or in any one particular, of the strictly objective incidents of the Biblical story which it enshrines, it is yet the poet's own epitaph and his condensed autobiography. All in all, now that those three great poems of Milton's later life have drawn permanently into their company the beautiful and more simple performances of his youth and early manhood, so that we have all his English poetry under view at once, the result has been that this man, who would have had to be remembered independently as the type of English magnanimity and political courage, is laurelled also as the supreme poet of his nation, with the single exception of Shakespeare.

Much light is thrown upon Milton's mind in his later life, and even upon the poems of that period, by his posthumous Latin *Treatise of Christian Doctrine*. It differs from all his other prose writings of any importance in being cool, abstract, and didactic. Professing to be a system of divinity derived directly from the Bible, it is really an exposition of Milton's metaphysics and of his reasoned opinions on all questions of philosophy, ethics, and politics. The general effect is to show that, though he is rightly regarded as the very genius of English Puritanism, its representative poet and idealist, yet he was not a Puritan of what may be called the first wave, or that wave of Calvinistic orthodoxy which broke in upon the absolutism of Charles and Laud, and set the English Revolution agoing. He belonged distinctly to that larger and more persistent wave of Puritanism which, passing on through Independency, included at length an endless variety of sects, many of them rationalistic and free thinking in the extreme, till, checked by the straits of the Restoration, it had to contract its volume for a while, and to reappear, so far as it could reappear at all, in the new and milder guise of what has ever since been known as English Liberalism. For example, the treatise shows that Milton in his later life was not an orthodox Trinitarian, but an anti-Trinitarian of that high Arian order, counting Sir Isaac Newton among its subsequent English adherents, which denied the coessentiality or coequality of Christ with absolute Deity, but regarded him as clothed with a certain derivative divinity of a high and unfathomable kind. It shows him also to have been Arminian, rather than Calvinistic, in his views of free will and predestination. It shows him to have been no Sabbatarian like the Puritans of the first wave, but most strenuously anti-Sabbatarian. Indeed one of its doctrines is that the Decalogue is no longer the standard of human morality, and that Christian liberty is not to be bounded by its prohibitions or by any sacerdotal code of ethics founded on these. Hence, in the treatise, not only a repetition of Milton's views on the marriage subject and of other peculiar tenets of his that had been set forth in his pamphlets, but some curious and minute novelties of opinion besides. By far the most important revelation of the treatise, however, consists in the very definite statement it makes of Milton's metaphysical creed and of the connexion of that creed in his mind with the revealed theology of Christianity. While, ontologically, he starts from a pure spiritualistic theism, or from the notion of one infinite and eternal Spirit as the self-subsisting God and author of all being, cosmologically his system is that of a pantheistic materialism, which conceives all the present universe, all that we call creation, as consisting of diverse modifications, inanimate or animate, of one primal matter, which was originally nothing else than an efflux or emanation from the very substance of God. Angels and men, no less than the brute world and the things we call lifeless, are formations from this one original matter, only in higher degrees and endowed with soul and free will. Hence any radical distinction between matter and spirit, body and soul, is, Milton holds, fallacious. The soul of man, he holds, is not something distinct from the body of man and capable of existing apart, but is actually bound up with the bodily organism. Therefore, when the body dies, the soul dies also, and the whole man ceases to exist. The immortality revealed in Scripture is, therefore, not a continued existence of the soul in an immaterial condition immediately after death, but a miraculous revival of the whole man, soul and body together, at the resurrection, after an intermediate sleep. In such a resurrection, with a final judgment, a reign of Christ, and a glorification of the saints in a new heaven and a new earth, Milton declares his absolute belief. But, indeed, throughout the treatise, with all its differences from the orthodox interpretations of the Bible, nothing is more remarkable than the profoundness of the reverence avowed for the Bible itself. The very initial principle of the treatise is that, as the Bible is a revelation from God of things that man could not have found out for himself, all that the Bible says on any matter is to be accepted implicitly, in the plain sense of the words, and without sophistication, however strange it may seem to the natural human reason. Hence, in all those essentials of Christianity which consist in the doctrines of the fall of man, atonement by Christ, and restoration and sanctification through Christ only, Milton is at one with the great body of Christians. Altogether, what the treatise makes clear is that, while Milton was a most fervid theist and a genuine Christian, believing in the Bible, and valuing the Bible over all the other books in the world, he was at the same time one of the most intrepid of English thinkers and theologians.

For further information reference may be made to Masson's *Life of Milton and History of his Time* (6 vols., 1859-80), and to his editions of Milton's *Poetical Works* (Cambridge edition in 3 vols., 1874, and smaller 3 vol. ed., 1882), as well as to Todd's variorum edition of the *Poetical Works*, with Life (5th ed., 1852), to Keightley's *Life, Opinions, and Writings of Milton* (1855), to *Milton und Seine Zeit* by Alfred Stern (1877-79), and to Mr Mark Pattison's *Milton* in Mr Morley's series of English Men of Letters. Collective editions of the prose works since that of 1698 are Symmons's (7 vols., 1806), Pickering's, with *Life* by Mitford (8 vols., prose and verse together, 1851), and St John's in Bohn's Standard Library (5 vols., 1848-53). This list includes a revised edition of Bishop Sumner's translation of the *Treatise of Christian Doctrine*, originally published in 1825. (D. MA.)

MILWAUKEE, the largest city in the State of Wisconsin, United States, is situated on the west shore of Lake Michigan, 100 miles north of its southern end, 80 miles north of Chicago, and 1000 miles north-west of New York by rail, in 43° 3′ N. lat., 87° 56′ W. long. (44 min. W. of Washington). The shore of the lake is 600 feet above the level of the sea.

The Milwaukee and Menomonee rivers unite in the centre of the business portion of the city, about half a mile from their entrance to Lake Michigan, where they are joined by a third and smaller stream—the Kinnikinnic. A bay 6 miles from cape to cape, and 3 miles broad, stretches in front of the city, which commands a fine water view, the ground rising along the shore 80 feet above the level of the lake, then gradually sloping westward to the Milwaukee river, and again rising on the west and north to a height of 125 feet. The ground also rises to a commanding elevation south of the valley of the Menomonee. Few cities present so many natural attractions of site, as indeed its Indian name indicates ("the beautiful hollow or bay"), and art has added to nature. In the residence parts of the city there are miles of avenues from 70 to 100 feet wide, lined on both sides with elms and maples, behind which stand handsome houses with spacious lawns, fountains, and evergreens, giving the appearance of a continuous park. The material used for building is largely the cream coloured brick made in the vicinity, from which Milwaukee is sometimes called the "Cream City." The climate, tempered by the great lake, is remarkably pleasant and healthy. The mean temperature, as shown by the records of twenty years, is 46°·7 Fahr. The coldest month is January (average 22°·37), the hottest July (70°·4).[1] During the last nine years the average death-rate has been but 20 per 1000, showing it to be one of the healthiest of American cities. Besides a full complement of the usual religious and charitable institutions, there is adjoining the city the national home for disabled United States volunteer soldiers, consisting of several buildings situated in grounds of 400 acres extent, which serve the purpose of a city park. There are numerous lodges belonging to the freemasons and other guilds; and the Turners' societies, which embrace a large membership and own some valuable buildings, have done much to create and keep up the practice of athletic exercises among the citizens. Two excellent musical societies are also established here.



Plan of Milwaukee

Before the year 1835 Milwaukee was known only as an Indian trading post occupied by a Frenchman named Solomon Juneau, who is generally spoken of as the founder of the city. The total inhabitants in 1838 numbered only 700; in 1840 there were 1712; but in 1846 the population amounted to 9666, in 1850 to 20,061, in 1855 to 30,118, in 1860 to 45,246, in 1870 to 71,440, and in 1880 to 115,578 (57,475 males, 58,103 females). In 1882 the population was estimated at 130,000,—more than one half of them of foreign parentage, a very large majority being Germans. Notwithstanding the multitude of nationalities represented in the population, there are few cities more orderly and law abiding, the number of police employed being less than one for every 1500 inhabitants. Another feature worthy of mention is the large proportion of families who own their own houses, and this is true not only as to the mercantile and professional classes, but especially as to the labouring population. Although the grain trade, formerly very large here, has now greatly diminished, the growth and prosperity of the city have not materially suffered, owing to the development of manufacturing industries, for which the low rents, healthy climate, and advantageous location make it well adapted. About a sixth of the population are engaged in the manufacture of clothing, cigars, cooperage, leather, bricks, sashes, doors, and blinds, machinery, and flour (of which one million of barrels are annually made), and in meat packing. Milwaukee has become famous for its "lager beer," of which there are one million of barrels annually produced, valued at $8,000,000. The lake commerce is very large. The tonnage entered and cleared in 1880 was 5,322,373 tons, being about as large as that of Baltimore, Boston, or Philadelphia. The Wisconsin Central, the Milwaukee and Lake Shore, the Milwaukee and Northern, and the Chicago, Milwaukee, and St Paul Railways have their head offices here, and the last named, owning 4000 miles of lines, has immense workshops in the Menomonee valley near the city.

Milwaukee is governed by a mayor and a common council of thirty nine aldermen. The streets and public buildings are under the charge of the board of public works, composed of three commissioners and the city engineer, all subject to the common council. A bountiful supply of water is obtained from the lake, and the streets are well supplied with sewers. The value of property as assessed for taxation was $62,000,000 in 1882,—the city debt being $2,500,000, mostly for the water works, which are city property.

---

[1] The monthly averages for twenty years are:—January, 22°·37; February, 25°·13; March, 33°·35; April, 43°·94; May, 53°·75; June, 64°·39; July, 70°·04; August, 67°·89; September, 61°·68; October, 48°·48; November, 36°·27; December, 25°·53.

There is an efficient system of public schools under a superintendent and board of school commissioners, the value of the buildings with their sites being estimated at $700,000. For the higher education there are a high school, a normal school, and three commercial colleges, while the Roman Catholics and Lutherans have several excellent denominational seminaries and colleges. A public library belonging to the city contained 20,000 volumes in 1882. (J. J.)

MIMICRY is the name given in biology to the advantageous resemblance (usually protective) which one species of animal or plant often shows to another. The word was first applied in this metaphorical sense by Mr W. H. Bates, and it has since been accurately defined and limited, in its biological application, by Mr A. R. Wallace. Briefly put, the essence of the phenomenon of mimicry consists in the following relation. A certain species of plant or animal possesses some special means of defence from its enemies, such as a sting, a powerful and disagreeable odour, a nauseous taste, or a hard integument. Some other species inhabiting the same district or a part of it, and not itself provided with the same special means of defence, closely resembles the first species in all external points of form and colour, though often very different in structure and unrelated in the biological order. For example, a South American family of butterflies, the *Heliconidæ*, are distinguished by their very varied and beautiful colours, and their slow and weakly flight; they might easily be captured by insectivorous birds but their remains are never found on the ground amongst the rejected wings of other butterflies which cover the soil in many places. They also possess a strong pungent odour which clings to the fingers for many days, and this fact led Mr Wallace to suspect that they have a disagreeable taste and would not therefore be eaten by birds after a single trial. Mr Belt has since experimentally proved the truth of that belief. But among the totally distinct family of the *Pieridæ*, most of which are white, there is a genus of small butterflies, known as *Leptalis*, edible by birds, some species of which are white like their allies, while the greater number exactly resemble one or other of the *Heliconidæ* in the peculiar shape and colouring of their wings. As regards structure, the two families are widely different; yet the resemblance of a species of one family to a species of the other is often so close that Mr Bates and Mr Wallace, experienced entomologists, frequently mistook them for one another at the time of capture, and only discovered their mistake upon nearer examination. Mr Bates observed several species or varieties of *Leptalis* in the Amazons valley, each of which more or less exactly copied one of the *Heliconidæ* in its own district. Accordingly, they seem to be mistaken by birds for the uneatable insects they mimic, and so to be benefited by their resemblance. This, which may perhaps be regarded as the most typical instance of true mimicry, is also the first to which the word was applied.

In considering the phenomena under review, it may be well to give first the chief observed facts, which are quite independent of any particular explanation, and then the theory which has been started to account for them by Mr Bates and Mr Wallace. Before doing so, however, true mimicry should be carefully discriminated from one or two superficially similar modes of resemblance among organic beings, whose real implications are very different. It must not be confused with mere accidental or adaptive resemblance, due either to simple chance or to similarity of external conditions. As a case of the first sort, we may adduce the real or fancied resemblance between certain orchids and flies or spiders; as a case of the second sort, we may take certain African *Euphorbiaceæ*, which, growing in dry deserts, have acquired a very close likeness to the cactuses that cover the equally dry deserts of Mexico; or again the sub-Antarctic gallinaceous bird, *Chionis alba*, which, living on the sea-shore, has acquired a coloration like that of the gulls, together with the legs of a wader. These resemblances, however, do not as such subserve any function. The species apparently mimicking and the species apparently mimicked either do not inhabit the same district or do not come into any definite relation with one another. The likeness is either accidental, or else it is due to similar adaptation to similar circumstances. In cases of true mimicry, on the other hand, the mimicking species derives a direct advantage from its likeness to the species mimicked; the resemblance is deceptive; and this is equally true whether we suppose the mimicry to be produced by creative design or by natural selection. On either hypothesis, however it came by its likeness, the mimicking species escapes certain enemies or obtains certain sorts of food by virtue of its resemblance to some other kind.

It should also be added that the word mimicry, as applied to such cases, is used only in a metaphorical sense. It is not intended to imply any conscious or voluntary imitation by one species of the appearance or habits of another. All that is meant is the fact of an advantageous resemblance, a delusive similarity, which gives the mimicking animal or plant some extra protection or some special means of acquiring food which it would not otherwise have possessed but for its likeness to the creature mimicked.

Taking animals first, mimicry does not occur very frequently among the higher classes. In the vertebrates it is comparatively rare, and among mammals probably only one good case has yet been adduced. This is that of *Cladobates*, an insectivorous genus of the Malayan region, many species of which closely resemble squirrels in size, in colour, and in the bushiness and posture of the tail. It has been suggested by Mr Wallace (from whom most of the following examples have been borrowed) that *Cladobates* may thus be enabled to approach the insects and small birds which form its prey under the disguise of the harmless fruit-eating squirrel. In this case, as in some others, the resemblance is not protective, but is apparently useful to the animal in the quest for food.

Among birds, Mr Wallace has pointed out that the general likeness of the cuckoo, a weak and defenceless group, to the hawks and gallinaceous tribe makes some approach to real mimicry. But besides such vague resemblances there are one or two very distinct cases of true mimicry in this class of vertebrates. In Australia and the Moluccas lives a genus of dull-hued honey suckers, *Tropidorhynchus*, consisting of large, strong, active birds, with powerful claws and sharp beaks. They gather together in noisy flocks, and are very pugnacious, driving away crows and even hawks. In the same countries lives a group of orioles, forming the genus *Mimeta*, and these, which are much weaker birds, have not the usual brilliant colouring of their allies the golden orioles, but are usually olive-green or brown. In many cases species of *Mimeta* closely resemble the *Tropidorhynchi* inhabiting the same island. For example, on the island of Bouru are found the *Tropidorhynchus bouruensis* and *Mimeta bouruensis*, the latter of which mimics the former in the particulars thus noted by Mr Wallace:—"The upper and under surfaces of the two birds are exactly of the same tints of dark and light brown. The *Tropidorhynchus* has a large bare black patch round the eyes, this is copied in the *Mimeta* by a patch of black feathers The top of the head of the *Tropidorhynchus* has a scaly appearance from the narrow scale formed feathers, which are imitated by the broader feathers of the *Mimeta* having a dusky line down each The *Tropidorhynchus* has a pale ruff formed of curious recurved feathers on the nape (which has given the whole genus the name of friar birds), this is represented in the *Mimeta* by a pale band in the same position Lastly, the bill of the *Tropidorhynchus* is raised into a protuberant keel at the base, and the *Mimeta* has the same character, although it is not a common one in the genus The result is that on a superficial examination the birds are identical, although they have important structural differences, and cannot be placed near each other in any natural arrangement Allied species of *Tropidorhynchus* in Ceram and Timor are similarly mimicked by the local *Mimeta* of each island Mr Osbert Salvin has likewise noticed a case of mimicry among the birds of prey near Rio Janeiro An insect-eating hawk, *Harpagus diodon*, is closely resembled by a bird eating hawk, *Accipiter pileatus* Here the advantage seems to be that the small birds have learned not to fear the *Harpagus*, and the *Accipiter* is able to trade upon the resemblance by catching them unawares, both birds being reddish brown when seen from beneath But the *Accipiter* has the wider range of the two, and where the insect eating species is not found it no longer resembles it, but varies in the under wing coverts to white Here again the resemblance, though advantageous, is not protective

Among reptiles, Mr Wallace has instanced some curious cases where a venomous tropical American genus of snakes, *Elaps*, with brightly banded colours, is closely mimicked by several genera of harmless snakes, having no affinity with it, but inhabiting the same region Thus the poisonous *Elaps fulvus* of Guatemala has black bands on a coral red ground, the harmless *Pliocerus æqualis* of the same district is coloured and banded precisely like it The likeness affords the unarmed snakes a great protection, because other animals probably will not touch them, mistaking them for the venomous kinds

It is among the invertebrates, however, and especially among insects, that cases of mimicry are most frequent and were first observed In the order *Lepidoptera*, besides the classical instance of *Leptalis* and the *Heliconidæ*, a genus of another family the *Erycinidæ*, also mimics the same group The flocks of one species of *Ithomia*, an uneatable butterfly, often have flying with them a few individuals of three other widely different genera, quite indistinguishable from them when on the wing In the tropics of the Old World, the *Danaidæ* and *Acræidæ* possess a similar protective odour, and are equally abundant in individuals they are closely mimicked by various species of *Papilio* and *Diadema* Mr Trimen, in a paper on "Mimetic Analogies among African Butterflies, gives a list of sixteen species or varieties of *Diadema* or its allies, and ten species of *Papilio*, each of which mimics a *Danais* or *Acræa* of the same region in the minutest particulars of form and colour The *Danais tytia* of India has semi transparent bluish wings, and a border of reddish brown, this coloration is exactly reproduced in *Papilio agestor* and *Diadema nama*, all three insects frequently coming together in collections from Darjiling In the Malay Archipelago the common and beautiful *Euplæa midamus* is so exactly mimicked by two rare species of *Papilio* that Mr Wallace generally mistook the latter at first for the ordinary insect An immense number of other instances among the *Lepidoptera* have been quoted from other parts of the world

Occasionally species of *Lepidoptera* also imitate insects of other orders Many of them take on the appearance of bees or wasps, which are of course protected by their stings. Thus the *Sesiidæ* and *Ægeriidæ*, two families of diurnal moths, have species so like hymenopterous insects that they are known by such names as *apiformis*, *vespiforme*, *ichneumoniforme*, *sphegiforme*, and so forth The British *sesia bombiliformis* closely resembles the humble bee, the *Sphecia craboniformis* is coloured like a hornet, and carries its wings in the same fashion Some Indian *Lepidoptera* have the hind legs broad and densely hairy, so as exactly to imitate the brush legged bees of the same country Mr Belt mentions a Nicaraguan moth, *Pionia lycoides*, which closely mimics a distasteful coleopterous genus, *Calopteron*, and Professor Westwood pointed out that the resemblance to the beetle is still further increased in the moth by raised lines of scales running lengthwise down the thorax

Among the *Coleoptera*, or beetles, and other orders, similar disguises are not uncommon Mr Belt noticed species of *Hemiptera* and *Coleoptera*, as well as spiders, in Nicaragua, which exactly resemble stinging ants, and thus no doubt escape the attacks of birds The genus *Calopteron* is mimicked by other beetles, as well as by the moth *Pionia* In the same country, one of the *Hemiptera*, *Spiniger luteicornis*, has every part coloured like the hornet, *Priocnemis*, which it mimics, "in its vibrating coloured wing cases it departs greatly from the normal character of the *Hemiptera*, and assumes that of the hornets ' Mr Wallace mentions the longicorn beetle, *Cyclopeplus batesii*, which "differs totally in outward appearance from every one of its allies, having taken upon itself the exact shape and colouring of a globular *Corynomalus*, a little stinking beetle, with clubbed antennæ" *Erythroplatis corallifer*, another longicorn, almost exactly resembles *Cephalodonta spinipes*, one of the common South American *Hispidæ*, which possesses a disagreeable secretion, and Mr Bates also found a totally different longicorn, *Streptolabis hispoides*, which resembles the same insect with equal minuteness Some of the large tropical weevils have the elytra so hard that they cannot be pierced by a bird's beak, and these are mimicked by many other comparatively soft and eatable insects In southern Brazil, *Acanthotritus dorsalis* closely resembles a *Curculio* of the hard genus *Heilipus*, and Mr Bates found *Gymnocerus cratosomoides*, a longicorn, on the same tree with the hard weevil, *Cratosomus*, which it mimics Other beetles resemble bees, wasps, and shielded bugs Hairy caterpillars are well known to be distasteful to birds, and comparatively free from attack, and Mr Belt found a longicorn, *Desmiphora fasciculata*, covered with long brown and black hairs, and exactly mimicking some of the short, thick, woolly caterpillars common on the bushes around

Amongst other orders, one of the most interesting cases is that of certain *Diptera* or two winged flies which mimic wasps and bees Sometimes this likeness only serves to protect the insect from attack, by inspiring fear of a sting But there are also a number of parasitic flies whose larvæ feed upon the larvæ of bees, as in the British genus *Volucella*, and these exactly mimic the bees, so that they can enter the nests or hives to deposit their eggs without being detected even by the bees themselves In every country where such flies occur they resemble the native bees of the district Similarly, Mr Bates found a species of *Mantis* on the Amazons which exactly mimicked the white ants on which it fed On the other hand, the defenceless species itself may mimic its persecutor, as in the case of several crickets, *Scaphura*, that exactly resemble various sand wasps, and so escape the depredations of those cricket killing enemies Another cricket from the Philippine Islands, *Condylodera tricondyloides*, so closely copies a tiger beetle, *Tricondyla*, that even Professor Westwood long retained it among that group in his cabinet, and only slowly discovered his mistake The cases here mentioned form but a small part of all those that have hitherto been observed and described in the insect world They amount altogether to many hundreds

Among plants, though included in the above definition for the sake of formal completeness, instances of true mimicry are rare or almost unknown Perhaps the nearest approach to this phenomenon in the vegetal world is found in the resemblance borne by the dead nettle, *Lamium album*, and a few other labiates, to the stinging nettle, *Urtica dioica* and *U urens* The true nettles are strikingly protected from animal foes by their stinging hairs, and the general appearance of the dead nettle is sufficiently like them to prevent human beings from plucking it, and therefore probably to deter herbivorous mammals from eating it down Mr Mansel Weale mentions another labiate, *Ajuga ophrydis*, of South Africa, which closely resembles an orchid, and may thus induce insects to fertilize its flowers Mr Worthington Smith has found three rare British fungi, each accompanying common species which they closely resembled, and one of the common species possesses a bitter and nauseous taste, so that this would seem to be a case of true mimicry Many diverse instances alleged by Mr A W Bennett, Dr Cooke, and others cannot be considered as genuine mimetic resemblances in the sense here laid down They are mere coincidences or similar adaptations to similar needs, and the word ought to be applied strictly to such likenesses alone as benefit the organism in which they occur by causing it to be mistaken for another possessing some special advantage of its own

The theoretical explanation of mimicry on evolutionary principles may best be considered in connexion with the general subject of protective coloration and variation in form, of which it is a very special case There are two ways in which imitative colouring may benefit a species It may help the members of the species to escape the notice of enemies or it may help them to deceive prey In the first case imitative hues enable the animal or plant to avoid being itself devoured, in the second case they enable it to devour others more easily, and so to secure a larger amount of food than less deceptively coloured compeers In the former instance we must suppose that such individuals as did not possess the deceptive colouring have been discovered and destroyed by enemies with highly developed sight, while those which possessed it have survived In the latter instance we must suppose that the individuals which have no protective colouring have failed to secure sufficient prey, through too readily betraying their presence, and that only those which possessed such colouring have become the parents of future generations It is difficult, however to separate these two cases, and in many instances the same colouring may aid a species both in escaping its peculiar enemies and in deceiving its peculiar prey They may therefore most conveniently be considered together

Colour is always liable to vary from individual to individual as we see in the case of domesticated fowls, rabbits, dogs, and other animals as well as in most cultivated flowers, wherever natural selection cannot act to keep the typical specific hues pure and true But in a wild state certain conspicuous colours are sure to prove disadvantageous by betraying the individual, and these will sooner or later get weeded out, under certain circumstances, either through the action of enemies or by starvation resulting from the inability to escape the notice of prey On the other hand, certain other colours are sure to benefit the individual by harmonizing with the tints of the environment and these will be spared by natural selection, so that the individuals possessing them will pair with one another, and will hand down their peculiarities to their descendants In this way many species will acquire and retain a coloration that harmonizes with their environment as a whole or with some special part of it The degree to which the protective coloration will be carried, however, must depend upon the sharpness of the senses in those other organisms which it is desirable to deceive Large dominant herbivorous or frugivorous mammals or birds, with relatively few enemies, would not be benefited by protective coloration, and so they seldom exhibit it The grasses or fruits on which they feed cannot make any attempt to escape them But carnivores generally require to deceive their prey, and therefore a large number of them exhibit marked deceptive colouring Still more especially do small defenceless birds or mammals need to escape the notice of the carnivores, and they accordingly very generally possess dull colours, because any variation in the direction of conspicuousness is certain to be promptly cut off Above all, among insects, which are so largely the prey of birds, of reptiles, and of other animals possessing highly developed vision, protective coloration in one form or other is almost universal, except where a nauseous taste, hairy skin, or hard external coverings afford a different kind of protection In every case the weeding out of ill protected forms must depend upon the relative keenness of vision in the various enemies or of the prey, be they mammals, birds, reptiles, insects, or spiders Hence the existence of protective coloring and of mimicry incidentally affords us valuable hints as to the perceptive faculties of the various classes against which each organism is thus unconsciously guarded

Where the general aspect of the environment is most uniform, and where little but a vague impression of colour without individual form can be conveyed, the hues of animals are also usually uniform, to match their surroundings, and no special imitative adaptations of form occur Thus, among the Arctic snows a brown or black animal would immediately be perceived, and if defenceless at once devoured, while if a carnivore it would seldom or never approach unperceived near enough to its prey to effect a capture Hence all such variations are at once repressed, and almost all Arctic animals, like the American polar hare, are pure white Elsewhere bears are black or brown, in the polar region the native species is nearly indistinguishable from the snow in which it lives Where the environment undergoes a regular change from season to season the colour of the fauna varies with it The Arctic fox, the ermine, the alpine hare, the ptarmigan and many other birds, are all more or less brown among the brown hill sides of autumn, and snow white among the winter snows Almost equally general is the sandy colour of deserts, though this, instead of being uniform, is slightly varied from grain to grain, and nearly all the birds, reptiles, and insects of Sahara exactly copy the sandy grey hue of the desert around them Soles and other flat fish (*Pleuronectidæ*) closely imitate the colour and speckled appearance of the sand on which they lie The fishes and crustaceans which inhabit the sargasso weed are coloured the same yellow as the masses of algæ to which they cling Aphides and many small leaf eating caterpillars are bright green like the neighbouring foliage

Where the environment is somewhat more diverse the resemblance begins to show more specialized features The lion a large ground cat of desert or rocky districts is uniformly brown, but the tiger and other jungle cats have perpendicular stripes which harmonize with the bamboos and brown grass of their native haunts, while the leopards jaguars and other tree cats have ocellated spots which conceal them among the mingled light and shade of the forests Large marine animals have the back black, because the water looks dark when seen from above, but their bellies are white so as to harmonize with the colour of the surface when seen from below Dr Weismann has shown that most edible unprotected caterpillars imitate the stripes and shades of the leaves among which they feed. Those which live upon grasses are longitudinally striped like the blades, those which live among small leaves are spotted and varied so as to resemble the distribution of light and shade in the bushes, and those which live upon large veined leaves with oblique ribs have oblique lines to harmonize with them In some cases even the unripe berries are represented on the caterpillar by small reddish spots A specialized form of this particular protective device is found in the chameleon, the chameleon shrimp many flat fish, and some amphibians, all of which can vary their coloration to suit that of the surface on which they rest The action is reflex, and ceases if the animal is blinded

Where the environment is very varied, as in tropical forests, we find the greatest variety of colouring as well as actual imitation of particular forms and the protective resemblances become at once closer and more common Birds, reptiles spiders, monkeys, and other active predaceous creatures are constantly hunting for insects and similar small prey amongst the fallen sticks or leaves, and among the most powerless classes of insects only those which very closely resemble specific objects in the environment can easily escape them A gradual passage can be traced from the most general to the most special resemblances under such circumstances. Many forestine birds have a ground tone of green in their plumage, which occurs nowhere but in the tropics Some tree lizards are green like the leaves on which they sit, others are marbled to resemble the bark where they lie in wait for their prey Arboreal snakes often hang like lianas or other creepers Insects which cling to the trunks of trees can seldom be distinguished from the bark A Sumatran butterfly, *Kallima paralecta*, always settles on dry bushes among dead leaves, and can then hardly be perceived among the brown foliage, which it imitates even in the apparent blotches and mildew with which its wings are covered The family of *Phasmidæ*, including the leaf and stick insects, carries such forms of imitation very far indeed Most of them are large, soft, defenceless creatures, but some, like *Phyllium*, closely resemble green leaves, so as to be almost indistinguishable while feeding; and others exactly imitate short broken twigs of bamboo Mr Wallace found one such insect, *Ceroxylus laceratus*, in Borneo, apparently overgrown with a creeping moss or jungermannia, and Mr Belt discovered a larval form in Nicaragua whose body was prolonged into thin green filaments, precisely like the moss in which it lurked In other instances the insect probably uses its disguise rather to deceive its prey than to escape its enemies Sir Joseph Hooker believes that an Indian *Mantis* deludes the little creatures which form its food by its singular likeness to a leaf, while Sir Charles Dilke found one which had its head and fangs moulded into the deceptive appearance of an orchid, so that small flies were actually attracted in search of honey into its very jaws Outside the class of insects, similar phenomena sometimes occur Thus according to Mr Bates, many showy little tropical spiders double themselves up at the base of leaf stalks so as to resemble flower buds, and thus delude the flies on which they prey Even among the vertebrates Mr Belt mentions a green Nicaraguan lizard looking like the herbage by which it is surrounded, and decked with leaf like expansions, which hide its predaceous nature from passing beetles or butterflies

These last instances are divided from true mimicry by a very narrow line But they differ in the fact that some vague object only in the general environment is simulated not a particular protected species, as in genuine mimetic resemblance If we allow, however, that natural selection can produce the white colour of Arctic animals, and the sandy hue of the sole and the flounder, it is easy enough to extend the same principle to the leaf insect and the stick insect, or even to real mimicry, as in the case of the *Leptalis* and the *Heliconidæ* Certain *Phasmidæ* may at first have varied in the direction of green coloration, and these would naturally escape the eyes of birds more readily than their fellows After the lapse of many generations, all the *Phasmidæ* of that special group would have become green, and the birds which preyed upon them would have learned in many cases to penetrate the disguise, for, as Mr Belt has observed each fresh deceptive resemblance in the prey is sure to be followed by increased keenness of discrimination in the enemies of the species At this stage the ordinary green *Phasmidæ* would often be killed, while only those which happened to approximate rudely in the venation of their wings to leaves would now escape the sharper and more experienced eyes of the birds Thus step by step the disguise would become more and more perfect only the best protected of each generation escaping on the average while all the worse protected would be discovered and devoured Given the usual luxuriance of tropical life, it is not difficult to understand how favourable variations might continually occur until at length we get such perfect deceptions as those of the leaf insects the stick insects and the moss grown larvæ

The phenomena of true mimicry may be explained by a parallel genesis Suppose to begin with a group of large and brilliant butterflies like the South American *Heliconidæ*, protected by a nauseous taste and odour and therefore never eaten by birds To such insects slow flight and conspicuous hues are a positive protection, because they enable birds readily to discriminate them and therefore prevent attacks just as the banded body of the wasp and the hum of the bee prevent us from catching and killing them upon a window pane Suppose again, that in the same district there lives a widely different species of edible butterfly presenting some very slight and remote resemblance to the protected species At first no doubt the resemblance will be merely an accidental one of general hue it may even be so slight as to deceive nobody except upon the most distant and casual glance Now suppose these edible butterflies to be devoured in large quantities by birds then a few of them may happen to gain safety by associating with the flocks of inedible butterflies which the birds refuse After a time, even if the habit of consorting with the protected species becomes fixed in the race the birds will begin to recognize the edible insects amongst the flocks, especially such as vary most in the opposite direction from the protected species On the other hand, they will overlook such as vary most in the same direction as the inedible kind and thus the least mimetic individuals will be destroyed, while the most mimetic will be left to pair with one another and to produce young most of whom will present the like peculiarities From generation to generation the birds will go on picking out every bad copy and sparing all the best ones, till at last the two species become absolutely indistinguishable upon the wing But the mimicry will never of course affect any but the most external and noticeable parts of the organism it will be to the last a mere matter of colour shape of wing visible appearance of legs or antennæ, and so forth The underlying structural differences will remain as great as ever though externally masked by the deceptive resemblance in form and hue

In like manner we may explain the genesis of the mimetic resemblance borne by *Volucella* to the humble bee Suppose an undisguised fly to enter the bees nest it would be at once attacked and killed. But if it presented some very slight resemblance to the bee it might manage to lay its eggs undisturbed, and its larvæ would then be able to feed quietly upon the larvæ of the bee With each new generation the more flimsy disguises would be more and more readily detected, and only those flies which varied most in the direction of resembling the bees would survive or lay their eggs in peace On the other hand, those which actually succeeded would possess great advantages over their neighbours, because their larvæ would thus obtain a safe and certain supply of food, and be guaranteed the protection of the bees nest In this way the flies would at last, by constant survival of the best adapted, come exactly to imitate the bees amongst which they lived

The theory of the origin of mimetic forms thus briefly sketched out is due to Mr Bates and Mr Wallace, and it explains all the facts more fully than any other It shows us, first, why the mimicking organism always imitates a specially protected species; secondly, why the two always inhabit the same district, thirdly, why the mimicking species is always much rarer than the species mimicked, fourthly, why the phenomenon is confined to a few groups only, and fifthly, why several different mimicking species often imitate the same protected form It also accounts for the absence of mimicry amongst large or dominant animals, and its comparative commonness amongst small and defenceless kinds And by affiliating the whole of the phenomena upon the general principles of protective colouring it reduces a seemingly strange and marvellous fact to a particular case of a well known law

Whatever theory be adopted, however, the facts and most of their implications remain the same For, whether we suppose these imitative resemblances to be due to direct creative design or to survival of favourable variations, it is at least clear that the disguise subserves a function—that it is purposive and not accidental Hence we may draw from the phenomena of mimicry certain important psychological implications On the hypothesis of evolution, it is obvious that the mimicry can never go further than the senses of the creatures against whom the disguise is advantageous would naturally carry it, and even on the hypothesis of special design it is not likely that the imitation would be made more accurate than would be necessary for practical purposes of deception There is much evidence in favour of this view Mr B T Lowne, for example, who has carefully measured the curvature of the facets in the compound eyes of insects upon which depends the minimum size of apprehensible objects, finds that the mimicry in the case of the flies parasitic upon bees nests has proceeded just so far as the structure of the bee's eye would lead us to expect, and no further In other words, so far as measurements of angular distance subtended can guide us, such a fly seems to be absolutely indistinguishable by a bee from one of his own species, within the limits of ordinary vision The pictures cast upon the sensorium by the fly and by a brother bee are simply identical In many other cases it can be shown that the mimicry seems specially intended to deceive the eyes of a particular class of animals, while there is no case of mimicry where the only enemies or prey consist of plants or eyeless animals Naturally there can be no mimicry without a creature to deceive, the very conception implies an external nervous system to be acted upon, and to be acted upon deceptively Thus mimicry in plants must have reference to the eyes of animals, in animals themselves to the eyes of one another We may conclude, accordingly, that if a leaf insect is green with faint violet brown veins to the wings, exactly like a certain leaf in order to deceive sundry tropical birds, then those birds are capable of perceiving the forms and colours imitated to that particular degree So the presence of mimicry in any group may guide us to a rough idea of the perceptive powers of those creatures whom the mimicry serves to deceive The exact imitation of sand and coloured pebbles in the flat fish is a fairly safe indication that the predaceous fish by whose selection they have been developed (through the weeding out of ill protected variations) can pretty accurately distinguish form and colour The long green pipe fish which cling around green sea weed have probably acquired their existing hues to deceive the eyes of small sharks, the *Phyllopteryx eques*, a hippocampus which looks precisely like a piece of tangled and waving fucus (see figure, vol xi p 852), has doubtless in the same way taken on its delusive likeness to the algæ among which it lives So the cricket which resembles its foe the sand wasp must have gained its present shape and hue by deceiving its enemy, and therefore it suggests the probability of highly developed vision on the part of the wasps There seems every reason to believe that in many instances insects, spiders, and even lizards have developed mimetic or other deceptive resemblances in order to delude the eyes of insects, while in other cases the disguise has been unconsciously adopted to deceive fish, amphibians, reptiles, birds, and mammals Moreover, we have some grounds for believing that the sense of colour is exceptionally strong in birds and in one or two insect orders, and the mimicry of colour seems to have proceeded to the greatest length amongst animals which are most exposed to the attacks of these classes or which would find it advantageous to deceive them. It may be added that these same classes have been most effective in producing the bright hues of flowers and fruits, on Mr Darwin's hypothesis, or are at least in any case most intimately correlated with such vegetable structures as fertilizers of blossoms and dispersers of seed Mimicry is thus to some extent a rough gauge of the perceptive faculties of the species deceived by it

The vocal mimicry which occurs among certain birds, such as the mocking bird, starling, parrot, and bullfinch, must of course be placed in a wholly different category from these biological cases. It is a direct volitional result, and it is mimicry in a literal not in a figurative sense The faculty seems to be due to the play instinct alone, and not to subserve any directly useful function (G A)

MIMNERMUS, a Greek elegiac poet, born at Smyrna, lived about 600 B C His life fell in the troubled time when the old Greek city of Smyrna was struggling to maintain itself against the rising power of the Lydian kings One of the extant fragments of his poems refers to the struggle and contrasts the present effeminacy of his countrymen with the bravery of those who had once defeated the Lydian king Gyges The poet mentions in another fragment that he belonged to the stock of the Colophonians who had seized the Æolic Smyrna But his most important poems were a set of elegies addressed to a flute player named Nanno, they were collected in two books called after her name Hermesianax mentions his love for Nanno, and implies that it was unfortunate Only a few fragments of these poems have been preserved, and their soft melancholy tone and delicate language give some idea of the poet s character His ideal is the sweet soft luxurious Ionian life, and he would enjoy it free from sorrow and die as soon as he could no longer enjoy it Yet there is apparent some of the old stronger strain of character which in early time raised the Ionian cities to greatness, pride in the glories of his race and scorn for those that are unworthy of their fathers' renown His experience of life was evidently sad, he felt that his country was gradually yielding to the enemy it had once defeated, and he knew that his own hopes were disappointed The sun himself has endless toils from rising to setting and again from setting to rising The life of man is as transitory as the leaves of spring, he says, referring to a passage in the popular epic poetry of Ionia (*Iliad*, vi 146) He wishes to die in his sixtieth year, a wish to which Solon replied bidding him reconsider and rather long to die when he was eighty years old Mimnermus was the first to make the elegiac verse, which had previously had more of the epic character, the vehicle for love poetry, and to impart to it the colour of his own mind He found the elegy devoted to objective themes, he made it subjective He set his own poems to the music of the flute, and the poet Hipponax says that he used the melancholy νομος Κραδιας He bears the epithet Λιγυασταδης, by which Solon addresses him It is doubtful whether this epithet is peculiar to himself or whether it marks him as belonging to a musical and poetic family or school, it is evidently akin to the epithet λιγειαι Μοῦσαι

MIMOSA The *Mimoseæ* (so named from their mimicry of animal movements) form one of the three suborders of *Leguminosæ*, and are characterized by their (usually small) regular flowers and valvate corolla Their 28 genera and 1100 species are arranged by Baillon in four series, of which the acacias (see ACACIA) and the true mimosas are the most important They are distributed throughout almost all tropical and subtropical regions, the acacias preponderating in Australia and the true mimosas in America The former are of considerable importance as sources of timber, gum, and tannin, but the latter are of much less economic value, though a few, like the talh (*M ferruginea*) of Arabia and Central Africa, are important trees Most are herbs or undershrubs, but some South American species are tall woody climbers They are often prickly The roots of some Brazilian species are poisonous, and that of *M pudica*, L, has irritating properties *M sensitiva* has been used in America in the treatment of fistula, &c, probably as an astringent The mimosas, however, owe their interest and their extensive cultivation, partly to the beauty of their usually bipinnate foliage, but still more to the remarkable development in some species of the sleep movements manifested to some extent by most of the pinnate *Leguminosæ*, as well as many other (especially seedling) plants In the so-called "sensitive plants" these movements not only take place under the influence of light and darkness, but can be easily excited by mechanical and other stimuli When stimulated, say at the axis of one of the secondary petioles, the leaflets move upwards on each side until they meet, the movement being propagated centripetally It may then be communicated to the leaflets of the other secondary petioles, which close (the petioles, too, converging), and thence to the main petiole, which sinks rapidly downwards towards the stem, the bending taking place at the pulvinus, or swollen base of the leafstalk See BOTANY, vol iv p 113, fig 117 When shaken in any way, the leaves close and droop simultaneously, but if the agitation be continued, they reopen as if they had become accustomed to the shocks The common sensitive plant of hot houses is *M pudica*, L, a native of tropical America but now naturalized in corresponding latitudes of Asia and Africa, but the hardly distinguishable *M sensitiva* and others are also cultivated The common wild sensitive plants of the United States are two species of the closely allied genus *Schrankia*

MINDANAO, MINDORO See PHILIPPINE ISLANDS

MINDEN, the chief town of a district of the same name in Prussia, province of Westphalia, is situated about 22 miles to the west-south west of Hanover, on the left bank of the Weser, which is spanned there by two bridges The older parts of the town retain an old fashioned appearance, with narrow and crooked streets, the modern suburbs occupy the site of the former fortifications The most interesting building is the Roman Catholic cathedral, the tower of which, dating from the 11th century, illustrates the first step in the growth of the Gothic spire in Germany The nave was erected at the end of the 13th century, and the choir in 1377–79 Among the other chief edifices are the old church of St Martin the town house, with a Gothic façade, the extensive court house, and the Government offices, constructed, like many of the other buildings, of a peculiar veined brown sandstone found in the district. Minden contains a gymnasium and several hospitals, besides other charitable institutions Its industries include linen and cotton weaving, dyeing, calico printing, and the manufacture of tobacco, leather, lamps, chicory, and chemicals There is also some activity in the building of small craft In 1881 107 vessels of an aggregate burden of 12,569 tons entered and cleared the river harbour of Minden The population in 1880 was 17,869

Minden (Mindun Mindo), apparently a trading place of some importance in the time of Charlemagne was made the seat of a bishop by that monarch and subsequently became a flourishing member of the Hanseatic League In the 13th century it was surrounded with a wall Punished by military occupation and a fine for its reception of the Reformation in 1547 Minden underwent similar trials in the Thirty Years' War and the wars of the French occupation In 1648 the bishopric was converted into a secular principality under the elector of Brandenburg From 1807 to 1814 Minden was included in the kingdom of Westphalia, and in the latter year it passed to Prussia In 1816 the fortifications, which had been razed by Frederick the Great after the Seven Years War, were restored and strengthened, and as a fortress of the second rank it remained the chief military place of Westphalia down to 1872, when the works were finally demolished. At Todtenhausen 3 miles to the north of Minden, the allied English and German troops under the duke of Brunswick gained a decisive victory over the French in 1759 About 3 miles to the south of Minden is the so called "Porta Westfalica,' a narrow and picturesque defile by which the Weser quits the mountains and reaches the plain

Minden is not to be confounded with the Hanoverian Munden, also sometimes written Minden (population 6355), at the confl (*Mundung*) of the Werra and Fulda.

MINE. See MINING

MINERALOGY

NATURAL objects which are homogeneous in their mass, and in which no parts formed for special purposes can be distinguished, are termed "minerals", and the branch of natural science which treats of these is termed mineralogy Minerals differ from the structures treated of in botany and zoology in the three following particulars (1) They differ in the mode of their formation, this has been accomplished, not by assimilation of matter, producing growth from within, but by augmentation of bulk through accretion of particles from without (2) Minerals are not heterogeneous While the objects treated of in the other departments of natural history consist of beings possessed of life, and having parts which, being mutually dependent, cannot be separated from one another without a more or less complete destruction of the individual, the objects treated of under the department of mineralogy have so uniformly consistent an individuality that they are not destroyed by any separation of parts,—each portion or fragment possessing the same properties and the same composition as the whole And (3), while those beings which are possessed of life have their component elements grouped into complexes, for the most part capable of more or less freedom of motion and susceptible of change, minerals have a constitution resulting from chemical attractions alone and an arrangement of their parts, under physical influences, which has resulted in rigidity and an absence of all tendency to change

FORM OF MINERALS—CRYSTALLOGRAPHY

Definition of a mineral

The most precise definition of a mineral would be—an inorganic body possessed of a definite chemical composition, and usually of a regular geometric form Of these, the second is in one respect the direct outcome of the first, while many of the most important physical properties possessed by minerals are outcomes of the second

Both the geometric form and the composition of minerals are produced and modified under the influence of general laws

Mineral bodies occur in the three physical conditions of solid, liquid, and gas Those now found in the last two states are few in number, and are of altogether inferior interest to those which occur as solids, but there is reason to believe that the minerals we know as solids once existed in the liquid or gaseous state, and that their present structure was determined in the process of solidification All bodies thus formed may be divided into two great classes —

Amorphous bodies

1 Amorphous bodies, or such as do not possess a definite and characteristic geometrical form These (when transparent) refract light singly in every direction (except when under stress), they are equally easy or equally difficult to break in all directions, when broken they exhibit a conchoidal or an earthy fracture, they are equally hard throughout all their parts, they are equally elastic in all directions, they conduct heat with equal rapidity and in equal amount in all directions

2 Crystalline bodies or such as occur in definite geometrical forms bounded by flat surfaces These present greater facilities of separation of their particles, or "cleavage," in certain directions lying in determinate planes than they do in others, most of them are neither equally hard nor equally elastic in all directions, conduct heat more rapidly in certain directions than they do in others, and, when transparent, refract light doubly except in certain directions

Mineral bodies are found in both of the above classes; and the same mineral body may occur in both the amorphous and the crystalline condition This is seen in the piece of gold shown in fig 1, where the upper portion has a sharply angular and a well defined shape, while the lower presents curvilinear and rugged outlines, similar to one another in no part Under favouring circumstances, it is possible that every substance whose composition is capable of being represented by a definite chemical formula—*i e*, which has an unvarying composition—may be capable of assuming a definite crystalline form

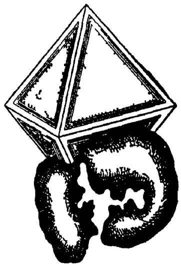


Fig 1

Size of crystals

Size and Form of Crystals —They are of every size from over a yard in diameter to mere specks requiring a high power of the microscope to reveal their existence Beryls have been obtained in America more than 4 feet in length by 2½ in thickness, weighing 2½ tons Equally large crystals of apatite have been found in Canada There is a rock crystal at Milan 3¼ feet long by 5½ in circumference, weighing 870 ℔ The highest perfection of form, and hence of other properties, is only found, however, in crystals of moderate or of small size

Variety of form

Variety of Form, and Constancy of Form —The same mineral may be found in different localities, or sometimes in the same locality, exhibiting an almost endless variety of forms Calc spar occurs at a Scottish locality in acicular pyramidal crystals of which the length may be ten or more times as great as the width (fig 2), in flat plates as thin as paper, in which the length is not the hundredth part of the width, also in prisms, pyramids, and rhombohedra, which at first sight (as in figs 3, 4) seem destitute of any relationship to each other This substance has elsewhere been noted in several hundred forms The minerals fluorite, pyrite, and baryte have each been observed in over a hundred diverse forms Nevertheless, however great the number, all the forms, in the case of each mineral, may be reduced or referred to a single type, by the simple process of examining its internal structure or the mode of arrangement of its molecules This is

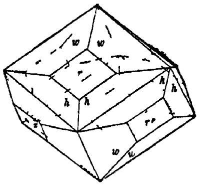


Fig 4

Fig 2

accomplished in two ways—(1) by finding the weak joints in that arrangement, through splitting the crystal, and (2) by measuring the angular inclination of the outside surfaces which bound the form and, from these measurements, by simple mathematical laws, arriving at what has been termed its "primitive" or simplest form

Invariability of angles.

As regards the mere recognition of a substance, such measurement in itself suffices,—the angular inclination, if the same surfaces be measured, being unvarying in each species It can, moreover, be shown that the possible range of external variety of form is governed by fixed mathematical laws, which determine precisely what crystalline forms are or may be produced for each species Comparatively few of these actually occur in nature, but crystallographic laws can point out the range of those which can possibly occur, can delineate them even before they are found, and can in all cases show the relationship which subsists between them and the simple or fundamental form from which or out of which they all originate It must be observed that in crystalline bodies the internal structure—that is, the arrangement of the molecules—is as regular in an outwardly shapeless mass as in the modelled crystal which presents itself as a perfect whole

Properties and parts of crystals

Definitions of Crystals, and their Members or Parts — A crystal is a symmetrical solid, either opaque or transparent, contained within surfaces which theoretically are flat, and of a perfect polish, but which are actually frequently curved, striated, or pitted These surfaces are called "planes," or "faces" The external planes of a crystal are called its "natural planes", the flat surfaces obtained by splitting a crystal are called its "cleavage planes' The intersections of the bounding planes are called "edges, and planes are said to be similar when their corresponding edges are proportional and their corresponding angles equal Crystals bounded by equal and similar faces are termed "simple forms' The cube, bounded by six equal squares, the octahedron, bounded by eight equilateral triangles, and the rhombohedron, bounded by six equal rhombs, are thus simple forms Crystals of which the faces are not all equal and similar are termed compound forms, or "combinations," being regarded as produced by the union or combination of two or more simple forms Edges are termed rectangular, obtuse, or acute, according as the angle at which the faces which form the edge meet is equal to, or greater or less than, a right angle Edges are similar when the planes by the intersection of which they are formed are respectively equal and equally inclined to one another, otherwise they are unlike or dissimilar

Interferences

When a figure is bounded by only one set of planes, it is said to be "developed" When an edge is cut off by a new plane, it is said to be "replaced", when cut off by a plane which forms an equal angle with each of the original faces which formed the edge, it is said to be "truncated" When an edge is cut off by two new faces equally inclined to the two original faces respectively, it is said to be "bevelled" When a solid angle is cut off by a new face which forms equal angles with all the faces which went to form the solid angle, it is said to be truncated

In classifying crystals and studying their properties, it is found convenient to introduce certain imaginary lines called "axes" Axes are imaginary lines connecting points in the crystal which are diametrically opposite,—such as the centres of opposite faces, the apices of opposite solid angles, the centres of opposite edges Different sets of axes may thus be drawn through the same crystal, but there is always one set, usually of three, but in one special class of crystals of four, axes, by reference to which the geometrical and physical properties of a crystal can be most simply explained. These axes intersect one another, either at right angles, producing "orthometric" forms, or at oblique angles, producing "clinometric" forms The axes may be all equal, or only two equal, or all unequal.

There is a definite conventional position in which for purposes of description a crystal is always supposed to be held With reference to this position one of the axes,—that which is erect or most erect,—is termed the "vertical," and the others the "lateral" The planes in which any two of the axes lie are called the "axial" or "diametral planes,"—sometimes "sections" By these the space around the centre is divided into "sectants" If there are, as is generally the case, only two lateral axes, the space is divided into eight sectants, or octants, but, if there are three lateral axes, it is divided into twelve sectants

Primitive forms

Primitive Forms of Crystals —If we attempt to arrive, through a study of the internal structure of crystals, as evidenced by directions of weakness of cohesion, at the total number of primitive or parent forms which can exist, we find that there are thirteen such forms and no more

Nine of these may be regarded as prisms standing upon a base, three as octahedra standing upon a solid angle, and there is one twelve sided figure, or dodecahedron

Prisms —Of the prisms eight have a four sided base

If the base is square and the prism stands erect—that is, if its sides or lateral planes as they are called, are perpendicular to the base—the form is termed a "right square prism (fig 6) In this the four lateral planes are rectangular and equal they may be either oblong or square, in the latter case the form is the "cube' (fig 5) When the base is a rectangle instead of a square, the form is a "right rectangular prism (fig 7) In each of the above three forms the edges are twelve in number In the cube all the edges are equal In the square prism the lateral edges are all equal, but are different from the four equal edges of the base In the rectangular prism two at each base differ in length from the other two, while both differ from the lateral, hence there are here three sets of edges four in each In each of the three forms, however, the solid angles are eight in number, all equal, and each enclosed by three right angles

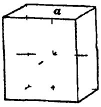


Fig 5

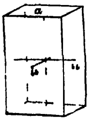


Fig 6

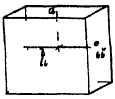


Fig 7.

When the base is a rhombus and the prism stands erect, the form is a "right rhombic prism (fig 8) Two of the angles in the base being here acute and two obtuse, two of the solid angles corresponding each with each must differ from the others So also must two of the lateral angles be acute and two obtuse The four lateral faces are equal

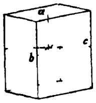


Fig 8

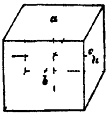


Fig 9

When the base is a rhomboid, and the prism stands erect, it is only the opposite lateral faces that can be equal The form is called a 'right rhomboidal prism' (fig 9)

When the base is a rhombus, but the prism stands obliquely on its base, the form is called an "oblique rhombic prism (fig 10). Here the basal edges of the lateral planes are all equal in length, but on account of the inclination of the prism the angles which these edges form with the lateral edges of the lateral planes are two acute and two obtuse

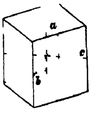


Fig 10

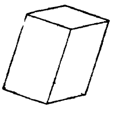


Fig 11

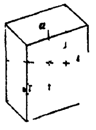


Fig 12.

If all the edges of an oblique rhombic prism are equal in length to the breadth of the base, and if the lateral planes are rhombi equal in all respects to the basal, the form is called a "rhombohedron" (fig 11). This is included within six equal planes, like the cube, but these planes have oblique angles The rhombohedron thus bears the same relation to the oblique rhombic prism which the cube does to the right square prism Of the eight solid angles of a rhombohedron only two are contained by three equal plane angles and these two 'apices, as they may be called, are opposite one another According as the apices are acute or obtuse, we have an *acute or obtuse* rhombohedron

When the base of an oblique prism is a rhomboid, the prism becomes an ' oblique rhomboidal prism (fig 12) In this form only diagonally opposite edges are similar, as regards equality of length and the value of the included angle Only opposite solid angles are equal as are also the opposite and parallel faces

A right prism may have an equilateral six sided base, it is then called an "hexagonal prism This form may be developed in two positions relatively to each other —one in which the transverse axes pass from the centres of opposite faces (fig 13), the other in which they pass from the centres of opposite edges of the planes (fig 14) The faces of the one set mutually truncate the edges of the other If a rhombohedron be positioned so as to rest upon one of its apices the faces of one hexagonal prism would truncate the lateral *edges* of the rhombohedron, while the faces of the other hexagonal prism would truncate its lateral *solid angles* Hexagonal prisms may be longer or shorter than the width of their bases The interfacial lateral angles are 120 The angle between the lateral and terminal faces is 90°

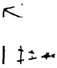


Fig 13 Fig 14

Octahedra —The planes of these eight faced solids are triangular, and they may be regarded as made up of two four sided pyramids applied to each other base to base They are always positioned so that they stand upon a solid angle with the basal plane —that is the plane which is the common base of the two pyramids—horizontal In the primitive forms now under consideration the vertices of the two pyramids will in this position be vertically above and below the centre of the base The upper and lower solid angles are then termed the 'vertical solid angles and the four lateral solid angles are called the basal solid angles

There are three octahedrons In the regular octahedron (fig 1ʳ the base is a square, and the eight faces are equilateral triangles of equal size There are twelve edges which are all equal The faces incline to each other at an angle of 109° 28 16 , and have the plane angles all 60 There are six equal solid angles When the base of the octahedron is square but the other edges, although equal to one another are either longer or shorter than the edges of the base, the form is a right square octahedron (fig 16) In this the faces are isosceles triangles the equal angles being at the basal edge of the planes These basal edges are equal and similar, but differ in length and in angles from the eight equal pyramidal edges When the base of an octahedron is a rhombus it is called a "right rhombic octahedron (fig 17

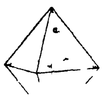


Fig 15

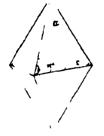


Fig 16

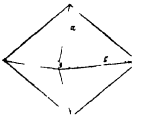


Fig 17

Dodecahedron —This (fig 18) has each of its twelve faces a rhombus It is like the cube and the octahedron, a solid which is symmetrical The interfacial angles are all 120° the plane angles are 109° 28 16 and 70° 31 44 The edges are twenty four and similar There are fourteen solid angles of which six are formed each by the meeting of four acute plane angles and eight by the meeting of three obtuse plane angles

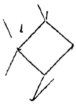


Fig 18

Determination of parent forms

It has been said that the above simple forms were arrived at through a study of the internal structure of crystals, chiefly as disclosed by cleavage Inasmuch, however, as there are some minerals which cleave in only one direction, and many which cannot be cleaved in any direction, this method of investigation fails Its employment, moreover, frequently led to conflicting or embarrassing results A conflicting result is when a substance has more than one set of cleavages,—that is, splits up in directions which would result in the production of more than one of the above primary or simple forms Thus the mineral fluorite occurs with much the greatest frequency in the form of the cube, and it might very consistently be held that its frequent occurrence in this form was a clear natural indication that the cube was the primary or simplest form of fluorite, but it splits up into an octahedron Galena crystallizes frequently in the form of the octahedron, yet to cleavage galena yields a cubic primary form It might be conceived that there had been, in each case, some special tendency to assume the cubic form and the octahedral form, but one and the same piece of rock may bear on its surface cubic crystals of fluor and octahedral crystals of galena,—each of the minerals having here assumed the primitive cleavage form of the other in preference to its own The mineral blende crystallizes not unfrequently in octahedra, which yield the dodecahedron on cleavage Fluor crystallizes in dodecahedra, yet yields the octahedron to cleavage Argyrite crystallizes in cubes and in octahedra, but yields the dodecahedron on cleavage Pyrite crystallizes in cubes, octahedra, and dodecahedra, and yields both the cube and the octahedron on cleavage

These are most embarrassing results, but they clearly indicate so intimate a relationship to subsist between three of the above simple forms that it is obvious that one alone would serve as a type form for representing the others The selection of that one should be based upon grounds of most eminent simplicity, and this again is to be arrived at by a consideration of the smallness of number of parts, *i e*, of faces, edges, and solid angles In such a consideration we find that the dodecahedron, with its higher number of each of these, at once gives place The cube has six faces, the octahedron eight, simplicity here is in favour of the cube The cube has twelve edges, the octahedron has twelve, in this respect they are equal The cube has eight solid angles, the octahedron six, here the greater simplicity is on the side of the octahedron So that this method of adjudicating by simplicity fails, and we are thrown back upon the relationships which may be unfolded through a consideration of the other elements of crystals,—their axes

Systems of Crystals and Laws of Crystallization

Relation of faces to axes

This consideration led, first, to the remarkable discovery that several of the above primary forms are mere modifications of each other, and ultimately showed that all crystals found in nature may be referred to six systems, based on certain relations of their axes, and that every face which could occur upon a crystal bears a definite and simple relation, in position and in angular inclination, to these axes

Axes directions of dominant accretion

As regards mere geometric measurement, there are several directions in which axes may with nearly equal advantage be projected For example, in the cube (fig 19) they may be drawn from the centres of opposite faces, as lettered O, or from opposite solid angles, lettered C, or from the centres of opposite edges, as lettered D There is abundance of evidence that each of these directions must be regarded as lines of dominant accretion of molecules

But the accretion may be not only dominant but overwhelmingly so in one only of these directions in certain cases, or existent along one set of axes alone in certain others In a specimen of native silver from Alva in Scotland (fig 20), along O this is so much the case that the concreting molecules have done little more than delineate the form of an octahedron, and this they have only been able to do by

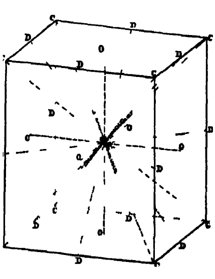


FIG 19 —Position of three sets of axes

aggregating themselves in lines of minute crystals of the very shape of which they were projecting the skeleton form. Moreover, a polar aggregation at the terminal ends of these octahedral axes is here shown by the amount of concreting and crystallizing

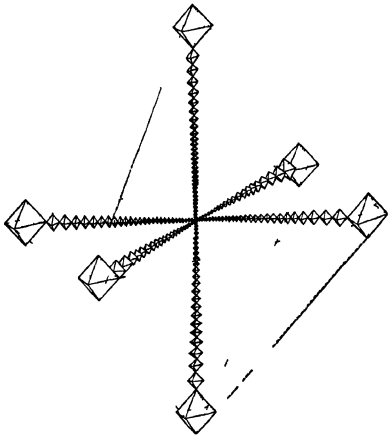


Fig 20

material being larger at the terminations of these axes than elsewhere. In the hollow faced cube again (fig 21) an aggregation of molecules in the direction of the lines D and C has filled the solid angles while none have been deposited along O.

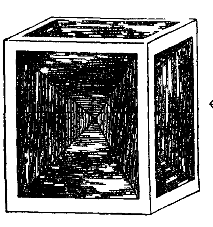


Fig 21

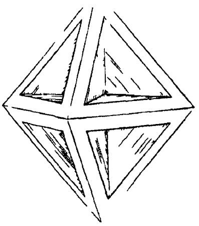


Fig 22

This occurs in crystals of salt. In the hollow faced octahedron again (fig 22) there has been no deposition of matter along the line C. Cuprite often shows this form, and it is frequently occurs in hollow faced dodecahedra wherein the vacuity is in the direction of D.

In the specimen of pyrite from Elba (fig 23) a deposition along D and C would ultimately have erected the scaffolding of a hollow cube in twelve lines of minute combinations of the cube and octahedron. Such directional arrangements may moreover not only be intermittent but often alternate. The pyrite from Traversella (fig 24) is an illustration of the first. A large pentagonal dodecahedron having been completed a new accession of material has been attached not uniformly spread over the pre-existent crystal to enlarge it but locally arranged in equal amount at the poles of O. But here the special method of the arrangement has determined the formation of a number of small crystals of the same form as that originally projected.

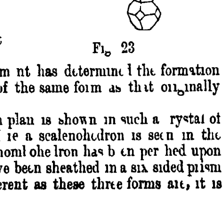


Fig 23

An alternation as it were in plan is shown in such a crystal of calcite as that in fig 25. Here a scalenohedron is seen in the centre of the figure, then a rhombohedron has been perched upon its summit, and lastly both have been sheathed in a six sided prism with trihedral summits. Different as these three forms are, it is found that they all here stand in a definite position one to the other; that definite position is the relation which they bear to one of the sets of axes, and this set may be assigned, not only to all the three crystals here combined, but also to all the crystals belonging to the same mineral wherever occurring. This general applicability constitutes one of the respects in which one special set of axes is in each of the systems, preferred to the others.

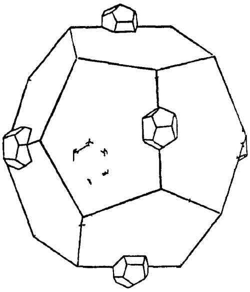


Fig 24

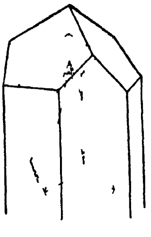


Fig 25

Coherence of particles not equal in all directions.

Another respect is the intensity with which the molecules cohere in the different parts of the crystal as referred to these axes, and the resultant different hardness of certain parts of crystals. It will be afterwards found that this obtains in a very limited manner in the crystals which belong to the first of the following systems, on account of its regularity and sameness as a whole. It may be laid down as a general rule that the edges of crystals are harder than the centres of their faces, and the solid angles harder than the edges. This is markedly the case in the diamond. But apart from this there is no distinctive hardness in any one part, side, or end of the crystals of the first system. It is otherwise with the crystals which fall to be considered in all the other systems. So different is the hardness of the various portions of these, so diverse the appearance of their parts in lustre, colour, polish, &c., so varying the amount of the recoil of these when struck, so unequal their power of conducting heat, so dissimilar their power of resisting the agencies of decay, and so irreconcilable their action upon transmitted light, that we cannot but conclude that the molecules which build them up are packed with greater force, if not in greater number, in certain directions in preference to others. There thus remains no question that these nature-indicated sets of axes are those along which there has been a specially selective or "polar" arrangement.

Systems of crystals

The six systems are founded upon the relationships of the axes in number, in length, and in angular inclination. All crystals may be divided into orthometric or erect forms and clinometric or inclined forms, and in similar manner may the systems be, through a consideration of the relative lengths of their axes, divided into three classes. In the first or most regular of these the axes are all equal, that is, they are of one length; in the second there is one axis which differs in length from the others, and therefore they are of two lengths; while in the third the axes are all unequal, and therefore they are of three lengths. Of the six systems one belongs to the first class, two to the second, and three to the third. Hence they are thus classed —

Monometric	*Dimetric*	*Trimetric*
Cubic	Tetragonal	Right Prismatic
	Hexagonal	Oblique Prismatic
		Anorthic

Though the grouping of the systems into three classes in virtue of axial dimensions is markedly borne out by optical and other properties, yet it is altogether insufficient for determining the relationships of the myriad forms in which bodies crystallize. Such knowledge is only attained by combining the consideration of axial length with axial inclination, and it is through a due regard of both of these that the six systems are instituted.

The above table may be read in two different ways, — either across or consecutively up and down the page. The six systems may be treated of in either of these ways, and there are certain advantages in considering them at least first by the former method

We consider first, as the more essential, the relative lengths of the axes, and, secondly, the angular inclination of these

1 In the cubic system the axes are all equal, and all intersect at right angles Here is the most perfect simplicity, and the most perfect regularity

2 In the tetragonal system two only of the axes are equal, but all still intersect at right angles Here is a departure from simplicity as regards the length of one axis, but no departure as regards the angular inclination

3 In the right prismatic system none of the axes are equal, but all still intersect at right angles Here is total loss of regularity in the first particular, but still none in the second

4 In the oblique prismatic system none of the axes are equal, and only two intersect at right angles Here there is again a total loss of simplicity in the first particular, and a certain amount of departure from it in the second

5 In the anorthic system none of the axes are equal, and none of them intersect at right angles,—so that here, as expressed by the name, there is a total departure from regularity in both particulars

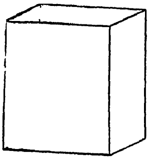


Fig 26

6 The hexagonal system is anomalous in relation to this mode of consideration It is regarded as having four axes, three of which lie in one plane, parallel to the base, and intersect each other at equal angles (necessarily angles of 60°) The fourth axis intersects these at right angles and may be longer, shorter or equal to them This system is generally considered after the tetragonal system, as having one axis which differs in length from the others, and only one which cuts the others at right angles By some a rhombohedron is considered as the primary of this system, it then comes to have three axes all equal, but none intersecting at right angles

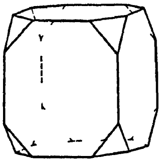


Fig 27

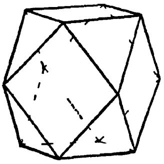


Fig 28

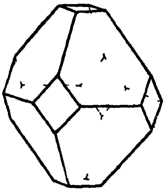


Fig 29

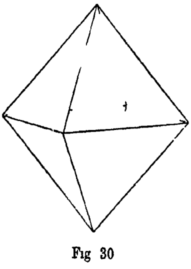


Fig 30

In considering these systems, or in describing the form of a crystal the vertical or erect axis is named the principal axis of the figure, and that axis is chosen as the vertical which is the only one of its kind In the cubic system there is no such axis, so that any one may be chosen as the vertical

It will be convenient, before proceeding to the consideration of the laws of crystallography and the combinations of forms,—especially in view of the terminology that must be employed in illustrating those general aspects of the subject,—to give an outline of one of the six systems here For this preliminary description the cubic system, as the simplest and most regular, naturally suggests itself as the most suitable

Cubic system

I *The Cubic System* —Here the axes are all equal, and all intersect at right angles The "cube" (fig 26), "octahedron' (fig 30), and "rhombic dodecahedron" (fig 33), which are here included, are alike in their perfect symmetry, the height, length, and breadth are equal, and their axes are equal, and are rectangular in their intersections

Relations of simple forms

In the cube (fig 5) these axes connect the centres of opposite faces, in the octahedron (fig 15) the apices of opposite solid angles, in the dodecahedron (fig 18) the apices of opposite acute solid angles The relation of these forms to each other, and the correspondence in their axes, will be made manifest through a consideration of the transition between the forms If a cube be projected with the axes in the above position, or if a model of it in any sectile material be employed, and if the eight angles are sliced off evenly, keeping the planes thus formed equally inclined to the original faces, we first obtain the form in fig 27, then that in fig 28 and fig 29, and finally a regular octahedron (fig 30), and the last disappearing point of each face of the cube is the apex of each solid angle of the octahedron Hence the axes of the former, being in no way displaced, necessarily connect the apices of the solid angles of the latter By cutting off as evenly the twelve edges of another cube, the knife being equally inclined to the faces, we have the form in fig 31, then fig 32, and finally the rhombic dodecahedron (fig 33), with the axes of the cube connecting the acute angles of the new form These forms are thus mutually derivable Moreover, they are often presented by the same mineral species, as is exemplified in galena, pyrites, and the diamond

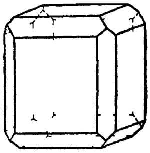


Fig 31

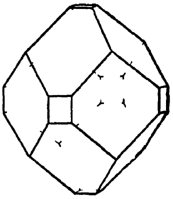


Fig 32

The process may be reversed, and the cube made from the octahedron, as will be readily understood from a comparison, in reverse order, of figs 26 to 30 Or the cube may be similarly derived from the dodecahedron, as seen by inspecting figs 33, 32, 31, 26

The octahedron also is changed to a rhombic dodecahedron by removing its twelve edges (figs 34, 35), and continuing the removal till the original faces are obliterated, thus producing the dodecahedron

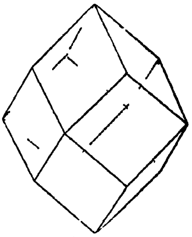


Fig 33

It will be observed that throughout all these changes the position of the axes, as determinants of dimensions, need not be altered,—that, in fact, one set of axes has served for all the forms

The relationships of the principal forms of this system being thus disclosed, the forms themselves have next to be considered

The cube (fig 26) is bounded by six equal squares, has twelve edges formed by faces meeting at 90°, and eight solid trigonal angles The axes are taken as joining the centres of each two opposite faces Examples are hallite, galena, and fluor

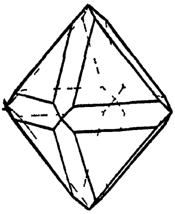


Fig 34

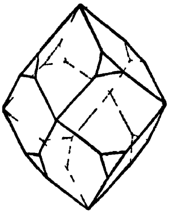


Fig 35

Octahedron The octahedron (fig 30), bounded by eight equilateral triangles, has twelve equal edges with planes meeting at 109° 28 16 , and six tetragonal angles The principal axes join the opposite solid angles Examples magnetite, gold, cuprite

Dodecahedron The rhombic dodecahedron (fig 33) is bounded by twelve equal and similar rhombi, has twenty four equal edges of 120°, and has six tetragonal and eight trigonal angles Each of the principal axes joins two opposite tetragonal angles Examples garnet, cuprite, blende

Tetrakishexahedron The tetrakishexahedrons (figs 36, 37, 38, varieties of icositetrahedron) are bounded by twenty four isosceles triangles, placed so as to form four sided pyramids on the faces of the cube, arranged in six groups of four each They have twelve longer edges, which correspond to those of the primitive or inscribed cube, and twenty four shorter edges placed over each of its faces The angles are eight hexagonal and six tetragonal, the latter joined two and two by the principal axes Examples fluorite, gold This form varies much in general aspect The four sided pyramid which rests on the edges of each face of the cube may be so low as almost to fall into it (fig 36), or it may rise so high that each side forms a level surface with that which is adjacent to it upon the nearest cubic face (fig 38) In the latter case the form has become the rhombic dodecahedron so that the more or less acute varieties of the form are but stages of a passage of the cube into the latter figure, through an increasing accretion of matter in the lines of the axes of the cube This is termed a "transition by increment

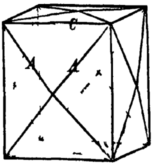


Fig 36

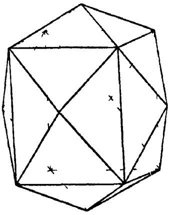


Fig 37

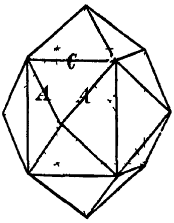


Fig 38

Triakisoctahedron The triakisoctahedrons, fig 39 (variety of icositetrahedron, fig 40), are bounded by twenty four isosceles triangles, in eight groups of three, arranged as pyramids on the edges of the faces of the octahedron Like the previous form they vary in general aspect, the variation here being from the octahedron on one side to the rhombic dodecahedron on the other, while the increased accretion here is in the direction of lines joining the centres of the faces of the octahedron or the solid angles of the cube The passage of the forms is similar to that illustrated in the last-considered form The edges are twelve longer, corresponding with those of the inscribed octahedron, and twenty four shorter, three and three over each of the faces The angles are eight trigonal and six ditetragonal (formed by eight faces), the latter angles joined two and two by the principal axes Examples galena, diamond

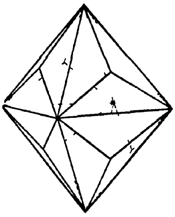


Fig 39

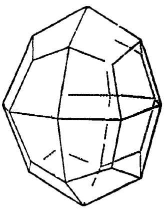


Fig 40

Icositetrahedron. The icositetrahedrons (fig 40) are bounded by twenty four deltoids This form varies from the octahedron to the cube, sometimes approaching the former and sometimes the latter in general aspect A four sided pyramid rests on the angles of the faces of the cube When increased accretion takes place along the cubic axes, an octahedron results When it is along lines joining the solid angles of the cube, that form itself results The edges are twenty four longer and twenty four shorter The solid angles are six tetragonal joined by the principal axes, eight trigonal, and twelve rhombic or tetragonal with unequal angles Examples analcime, garnet

Hexakis-octahedron. The hexakisoctahedrons (fig 41), bounded by forty eight scalene triangles, vary much in general aspect, approaching more or less to all the preceding forms, into all of which they may pass, but most frequently they have the faces arranged either in six groups of eight on the faces of the cube, or eight of six on the faces of the octahedron, or twelve of four on the faces of the dodecahedron There are twenty four long edges, often corresponding to those of the rhombic dodecahedron or bisecting the long diagonal of the trapezohedron, twenty four intermediate edges lying in pairs over each edge of the inscribed octahedron, and twenty four short edges in pairs over the edges of the inscribed cube There are six ditetragonal angles joined by the principal axes, eight hexagonal, and twelve rhombic angles Examples diamond, fluorite

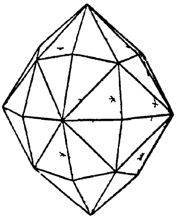


Fig 41

General Laws of Crystallography —The seven forms of crystals now described are related to each other in the most intimate manner This will appear more distinctly from the account which is to follow of the mode of derivation of the forms, with which is conjoined an explanation of the crystallographic signs or symbols by which they are designated These symbols were introduced by Naumann, in the belief that they not only mark the forms in a greatly abbreviated manner, but also exhibit the relations of the forms and combinations in a way which words could hardly accomplish In order to follow out this derivation of forms, it is necessary to state briefly the following laws, which have been established in crystallography It is to be remembered that these laws apply, not merely to the cubic system just described, but to all the systems

1 *The Law of the Invariability of the Angles of Crystals*, which was established by Romé de l Isle, may be thus stated —the angles of inclination of the faces of a crystal are constant, however unequally the faces may be developed The corresponding angles of different crystalline specimens of the same body do not, however, always absolutely agree Differences have been found, amounting sometimes even to 10

Symmetry 2 *The Law of Symmetry*, discovered by Hauy, may be thus expressed —(1) similar parts of crystals—faces, edges, angles, and consequently axes—are all modified in the same manner, and dissimilar parts are modified separately or differently, (2) the modifications produce the same effect on the faces or edges which form the modified part, when they are equal, when they are not equal, they produce a different effect That is, if an edge be truncated or bevelled, every similar edge will be similarly truncated or bevelled, if an angle be truncated or acuminated, every similar angle will be similarly truncated or acuminated, and consequently every similar axis will be equally affected by the modifications Thus the cube has eight similar angles and twelve similar edges In the physical production of the cube, if one of the angles or edges be modified, all will be similarly modified This, which is the most important law of crystallography, is, however, subject to an exception which was fully formulated by Weiss The law was—all the similar parts of crystals, faces, edges, angles, and consequently axes, are modified at the same time and in the same manner, the forms resulting from this law are termed "holohedral ' The exception is that half of them or one fourth of them only may be similarly modified When only half of the similar parts are modified, we get the "hemihedral forms, when one fourth only are modified, which occurs only rarely, we get "tetartohedral forms

Parallelism of faces 3 *The Law of the Parallelism of the Faces of a Crystal*, discovered by Romé de l Isle, may be expressed as follows —every face of a crystal has a similar face parallel to it, or every figure is bounded by pairs of parallel faces (with the exception of certain hemihedral forms)

Zones 4 *The Law of Zones*, first established by Weiss, may be thus enunciated —the lines in which several faces of a crystal intersect each other (or would do so if they were produced until they met) frequently form a system of parallels Such a series of faces is termed a "zone ' Sometimes the zones are parallel to one of the symmetrical axes Thus, in every prism, the faces of the prism constitute a zone which encircles the axis of the prism Faces may be in a zone although they do not actually intersect on the form

5 *The Law of the Rationality of the Parameters* of the faces of crystalline series, first indicated by Malus, is that the position of planes may be assigned by numbers bearing some simple ratio to the relative lengths of the axes of the crystal This law was the outcome of investigations into the relationship of forms glanced at in commencing the consideration of the cubic system, and was arrived at through the study of the mode of derivation of forms

Derivation of forms The derivation of forms is that process by which from one form chosen for the purpose and considered as the type – the fundamental or primary form —all the other forms of a system may be produced, according to fixed principles or general laws In order to understand this process or method of derivation it must be noted that the position of any plane is fixed when the position of any three points in it, not all in one straight line is known To determine the position, therefore, of the face of a crystal, it is only necessary to know the distance of three points in it from the centre of the crystal, which is the point in which the axes intersect each other As the planes of all crystals are referred to their axes, the points in which the face (or its supposed extension) meets the three axes of the crystal are chosen, and the portions of the axes between these points and the centre are named parameters of the face, and the position of the face is sufficiently known when the relative length or proportion of these parameters is ascertained When the position of one face of a simple form is thus fixed or described, all the other faces of the form are in like manner fixed in accordance with law 2, since they are all equal and similar, and have equal parameters—that is, intersect the axis in the same proportions Hence the expression which marks or describes one face marks and describes the whole figure, with all its faces

The octahedron is adopted as the primary or fundamental form of the cubic system, and distinguished by the first letter of the name, O Its faces cut the half axes at equal distances from the centre, so that these semiaxes, the parameters of the faces, have to each other the proportion 1 1 1 In order to derive the other forms from the octahedron, the following construction is employed

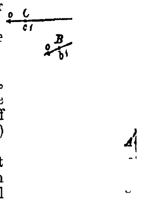
Proportion of parameters expressed by symbols. Notation of Naumann. Suppose a plane to be laid down perpendicular to one axis, and consequently parallel to the two other axes (or to cut them at an infinite distance, expressed by ∞, the sign of infinity), then the hexahedron or cube is produced, designated by the crystallographic sign ∞O∞,—expressing the proportion of the parameters of its faces, or ∞ 1 ∞ If a plane is supposed placed on each edge, parallel to one axis, and cutting the two other axes at equal distances, the resulting figure is the rhombic dodecahedron, designated by the sign ∞O, the proportion of the parameters of its faces being ∞ 1 1 The triakisoctahedron arises when, on each edge of the octahedron, planes are placed cutting the axis not belonging to that edge at a distance from the centre *m*, which is a rational number greater than 1 The proportion of its parameters is therefore *m* 1 1, and its sign *m*O, the most common varieties are $\frac{3}{2}$O, 2O, and 3O, seen in diamond and fluorite When, on the other hand, from a similar distance *m* in each two semiaxes prolonged a plane is drawn to the other semiaxis, or to each angle, an icositetrahedron is formed, the parameters of its faces have consequently the proportion *m* *m* 1, and its sign is *m*O*m* the most common varieties are 2O2 and 3O3 —the former very frequent in leucite, analcime, and garnet, the latter in gold and amalgam When, again, planes are drawn from each angle or the end of one semiaxis of the octahedron parallel to a second axis and cutting the third at a distance *n* greater than 1 then the tetrakishexahedron is formed, the parameter of its faces is ∞ *n* 1, its sign is ∞O*n*, and the most common varieties in nature are ∞O$\frac{3}{2}$, ∞O2, and ∞O3 Finally, if in each semiaxis of the octahedron two distances *m* and *n* be taken, each greater than 1, and *m* also greater than *n* and planes be drawn from each angle to these points so that the two planes lying over each edge cut the second semiaxis belonging to that edge at the smaller distance *n* and the third axis at the greater distance *m*, then the hexakisoctahedron is produced the parameters are *m* *n* 1, its sign *m*O*n*, and the most common varieties 3O$\frac{3}{2}$, 4O2, and 5O$\frac{5}{3}$, seen in diamond and fluorite

It must be observed that the numbers in the above signs refer to the parameters of the faces —not to the axes of the crystal, which are always equal One parameter also has always been, in the above, assumed =1, and then either one only of the two other parameters, marked by the number before O or both of them, marked by the numbers before and after O, have been changed

In the above consideration of the mode of derivation of these forms actually found in nature which belong to the cubic system, it will be observed (though the illustrations were limited) that the value of *m* and *n* in these indicated by the precision of the proportions $\frac{3}{2}$ 2 or 3, a definite numerical relationship This at once led up to the extended observations which established the law above stated of proportionality in the modification of crystals, or the rationality of the parameters which gives a mathematical basis to the science, adding to symmetry of arrangement a numerical relation in the position of the planes

To illustrate this in a general form (and not merely with special reference to the mode of notation or expression of Naumann, which is that adopted in the subsequent descriptions), let AOA, BOB′, COC (fig 42) be the three axes of a crystal, drawn in perspective, and cutting one another in the centre O The semiaxes OA, OB, OC are three parameters Now in the line OA take $Oa_2 = \frac{1}{2}OA$, and $Oa_3 = \frac{1}{3}OA$,—making as many points as may be necessary between OA, *rational fractions* of OA Subdivide OB and OC in a similar manner Further produce OA, OB, OC to A*o*, B*o*, C*o*, in each direction to an infinite distance, or to a supposed infinite distance, as expressed by the arrow head, and suppose these extended axes to be divided in a manner similar to the subdivisions of the parameters by rational multiples of OA, OB, and OC *All the planes of a crystal will be parallel to one or other of the planes which pass through three of the points thus determined*

First, in order to apprehend the relationship of faces to these axes, or to the half axes,—the parameters of the faces,—let us suppose one plane of a crystal to be so situated as to cut the three parameters OA, OB, OC at their extremities A, B, C, which it must be remembered are points equidistant from the centre or let it be supposed that a glass plate rests upon three intersecting wires at such points It is evident that such a plane or plate will have a definite inclination or slope Suppose further a second plane or plate to exist which cuts the three semiaxes in the points a_2 b_2, c_2 which have been measured off (along with a_1 b_1 c_1) as equidistant from O It will be evident that such a plane, though smaller will be parallel to the first seeing that, like it, it cuts the three parameters at equal distances from O



A little consideration will show that, whatever the absolute distances from the centre may be so long as the supporting subdivisions are equal no new slope of the glass plates or planes is possible, planes so situated must be parallel and similar Any sign which may be adopted to express the slope of one of such planes must be applicable to all A plane, however, cutting the points a_1, b_1 c_2 will have quite a different slope

Let us now suppose a plane to cut a different set of the semiaxes, namely OA, OB OC, in the points $-a_1$, $-b_1$, $-c_1$ Such a plane would be parallel to one cutting the points $-a_2$, $-b_2$ $-c_2$ and also to the set of planes first described, but on the opposite side of the centre of the crystal If again, however, we had a plane cutting the semiaxes OA and OB in $-a_1$ $-b_1$ but the semiaxis OC in the point $-c_2$ it is clear that the slope of this plane would be quite different from that of the planes just described, but it would be parallel to the plane cutting the points a_1, b_1, c This slope, like the other evidently depends not on the absolute lengths of the portions of OA, OB OC cut off but upon their proportions or ratios and such is the case with all the planes which are referred to the same axes

As there are three axes, and each or all of them may be cut at any points and at any ratios it is evident that the number of planes which is possible is infinite, and it must be also evident that the inclinations of all are fixed or determinate if we know the ratios While, however the possible number of planes is infinite the actual number occurring among minerals is either small or moderate, in virtue of the fact that the ratios of subdivision of the axes are always simple and not numerous

Naumann's symbols for the notation or individualizing of planes have been glanced at A simpler method is that of employing as indices the denominators (if simple fractions) of the fractional parts of the axis cut Thus 111 is used for any plane parallel to that cutting the axes in a_1 b_1 c_1 122 for those parallel to a_1 b_2 c_2 313 for a_3, b_1, c_3 and so on

When any of the points referred to have negative signs the corresponding indices have negative signs placed over them Thus $\bar{1}22$ is the index for a plane parallel to a_1b_2c 103 is the index of the plane a_1 $b\infty$ c_3 ∞ here indicates infinity that is the plane never would cut the axis B however far it were extended in other words it is parallel to it The necessity for elongating the axes is brought about by the occurrence of highly acuminating planes, which in many cases would not meet the axes at all unless these were prolonged

If the axes are unequal, as in the trimetric forms then the ratio is of the same character except that the relative lengths of the axes come into consideration but here, as in the regular system, irrational values cannot occur, and in even the most complex crystals they seldom exceed seven, either as aliquot parts or multiples

It will thus be seen that in crystals there is no haphazard scattering of faces but a complete subserviency to law a law which may be said to be the linear equivalent to the law of multiple proportions by weight and Gay Lussac's law of multiple proportions in combination by volume

In abbreviation of all the systematic modes of notation letters of the Latin and Greek alphabets are frequently employed in a [illegible] less arbitrary manner and with advantage in the case of complex forms

Symmetry of combination.

6 *The Law of Symmetry of Crystalline Combination* is the consequence of the law of symmetry and the law of the rationality of the parameters, and has been partially stated in enunciating these laws It is thus expressed:—(1) a substance can only crystallize in forms, whether simple or compound, which have the same relative symmetry, that is, belong to the same crystalline system, and the parameters of the faces of which bear a simple relation to each other, that is, belong to the same axis, (2) a form cannot be modified by faces belonging to a different system, or a different series

Apparent exceptions

Certain exceptions to the first part of this law occur The element carbon occurs as the diamond, which is cubic, and as graphite, which is hexagonal Sulphur occurs near volcanoes in needle crystals belonging to the oblique prismatic system, and also in caves (deposited apparently from solution) in crystals belonging to the right prismatic system Titanic acid is tetragonal in rutile, and right prismatic in brookite Carbonate of lime is hexagonal in calcite, and prismatic in aragonite These are probably only apparent exceptions The elementary substances which go to form them occur in different allotropic states, with different amounts of specific heat, and it is probable that in these different states they go to form the above modifications, which are therefore, in every respect, except in their chemical composition, different mineral bodies The physical differences between diamond and graphite may suffice as an illustration The diamond is transparent, colourless, brittle, and extremely hard, graphite is opaque, black, tough, and so soft as to be utilized as a lubricant

Spheres of Projection—The foregoing scheme for the development of the relation which subsists between faces of crystals and their axes affords but slight aid in displaying the position of the faces, or their mutual relationships The delineation even of a considerable series of crystal forms does not indeed go far in effecting this,—on account, first, of very unequal development in the size of the faces of crystals, and, secondly, on account of the *habit* of development of these face not only differing largely, but being special to certain localities,—as in the entire absence of some faces, and in the preponderance of others

Maps of the whole domain occupied by the forms of each mineral have been happily projected for such display The projection is laid down as on a globe, in accordance with stereographic projection, and admitting of calculation according to the laws of spherical trigonometry These globe maps are called "spheres of projection The centre O is the common centre of the crystal and of the sphere in which the axes intersect The three axes will of course meet the circumference of the sphere in six points called the "poles of the axes" From the centre radii are supposed to be drawn, meeting each plane perpendicularly It is evident that such radii will have fixed inclinations to each other They are called 'normals to the planes, and the points in which when produced they meet the circumference of the sphere of projection are called the ' poles of the corresponding faces A face and its pole thus call for only one symbol The angle included by any two normals is the supplement of that included by the two corresponding faces

Zones.

It is thus easy to determine the angles of any two normals when that of the corresponding faces is known, or *vice versa* Thus, if the angle between two faces 125°, that of the normals will be 55° The spheres of projection are specially adapted to enable us to avail ourselves of the aid to calculation afforded by the forenoted fact that sets of faces lie parallel to each other, forming zones for, when projected on such a sphere, the normals of the parallel faces will all lie in one plane and the poles all cutting its surface in the direction of one line may be connected, and so form a great circle on the sphere This is called the "zone circle" A line drawn through the centre of the zone plane, cutting it at right angles, is the "zone axis", it is parallel to all the faces, and intersections of the faces (if they are extended enough to intersect), of the zone. A face may be common to two or more zones, its normals will then coincide with the intersections of the several zone planes.

In the absence of actual spheres upon which to detail the facts which go to form the "sphere of projection" of each substance the hemisphere is represented on a plane surface. This has of necessity the disadvantage, except as regards the circumferential zone, of introducing spherical distance distortion—foreshortening of all parts lying near the circumference, but the eye soon gets accustomed to this. Fig 43 presents the principal zones of the cubic system, and

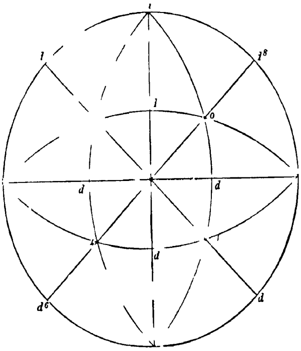


Fig 43

shows the position of the poles of the faces of the cube, the octahedron, and the rhombic dodecahedron. o_1, o_2, o_3, &c, are the poles of the octahedral faces, a_1, a_2, a_3, &c, those of the faces of the cube, and d_1, d_2, d_3, &c, those of the rhombic dodecahedron. It will be observed that the faces of the cube fall into the zone circles of the octahedron and dodecahedron, while those of the octahedron fall into those

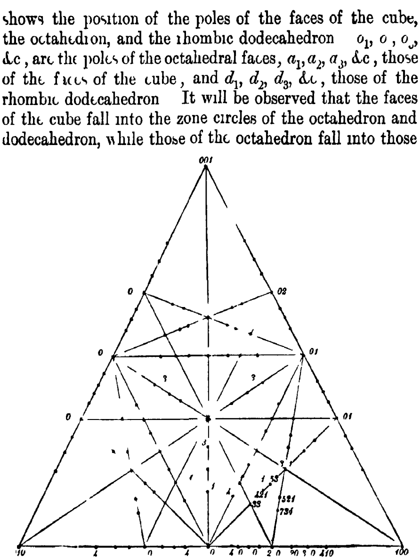


Fig 44 —Principal Poles of Cubic System in Octant of Sphere

of the rhombic dodecahedron. Considering this as a delineation of a globe, these zone circles come to represent latitude and longitude, and, as almost all the faces in this system fall into some zone circle, it is clear that the latitude and longitude of all normals may be readily laid down, and their relations at once determined by spherical trigonometry. Fig 44 shows the arrangement of the poles of all the forms belonging to the cubic system noticed above, or referred to in the present article,—delineated on an octant of the sphere of projection. It displays the perfect regularity of the system.

Hem
hedr
form

Hemihedral and Tetartohedral Forms.—The exception to the second law (that of symmetry), which was formulated by Weiss, was to the effect that one half or even one fourth only of the faces which go to form a holohedral crystal may be present. When but one half of the faces present themselves the form is termed hemihedral, when only one fourth it is tetartohedral. These restrained developments have now to be considered. In hemihedral forms the development is restrained but symmetry is not deranged, half the similar parts are still alike, though unlike the other half.

There are two classes of hemihedral forms:—

I. Those forms in which half the similar angles or edges are modified independently of the other half ("hemiholohedral"), producing—

1. In the monometric and dimetric systems tetrahedral and sphenoidal forms by the independent replacement of the alternate angles; then opposite faces are not parallel and they are hence called inclined hemihedrons, as in chalcopyrite, boracite.[1] The replacement in the dimetric system of two opposite basal edges at one base and the other two at the opposite base is of the same kind, as in edingtonite.

2. In the trimetric system "monoclinic" forms by the replacement of half the similar parts of one base and the diagonally opposite of the other unlike the other half, as in datholite, humite.

3. In the trimetric and hexagonal systems hemimorphic forms, by independent replacements at the opposite extremities of the crystal, as in topaz, calamine, tourmaline.

4. In the rhombohedral system, by the replacements of the alternate basal edges or angles of the rhombohedron forms usually called tetartohedral or quarter forms, on the ground that mathematically the rhombohedron is a hemihedral form derived from the hexagonal prism which is the type of the hexagonal system. Rock crystal is usually developed according to this law.

II. Those forms in which all the similar angles or edges are modified but by half the full or normal number of planes ("holohemihedral") producing—

1. In the monometric system pyritohedral forms, by a replacement of the edges or angles, as in pyrites. Such forms have opposite faces parallel and are often called parallel hemihedrons.

2. In the dimetric system pyramidal and sphenoidal forms, by a replacement of the eight solid angles of the primary prism, according to two methods.

3. In the hexagonal system "pyramidal" and "gyroidal" forms, by a replacement of the solid angles of the hexagonal prism, or of the six lateral angles of the rhombohedron, according to two methods, as in quartz and apatite.

The above illustrations show that hemihedrism is not only divided into two classes but is of various kinds, and these have been systematized as follows:—holomorphic, in which the occurring planes pertain equally to the upper and lower (or opposite) ranges of sectants, as in ordinary hemihedrons; and (2) hemimorphic, in which each set of planes pertains to either the upper or the lower range but not to both. As to the relative position of the sectants which contain the planes, the forms may be vertically direct, as in baryte, vertically alternate, as in the tetrahedron, the rhombohedron, and the plagihedral faces of quartz, and vertically oblique, as in many forms of chondrodite.

Hen
mor
forn

In hemimorphic forms symmetry is deranged, the crystals are bounded at the opposite ends of their main axes by faces belonging to distinct forms or modifications—always however of the same system; hence only the upper or the under half of each crystal can be regarded as complete as regards the form there seen, and so for each end it is half formed.

Fig 45 represents a crystal of tourmaline which is bounded on the upper end by the planes of the rhombohedrons R (P) and $-2R$ (o) and on the lower end by the basal pinacoid (k). In fig 46 of smithsonite the upper extremity shows the base k, two brachydomes o and y and two macrodomes m and l,

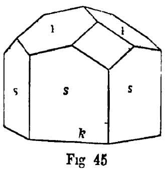


Fig 45

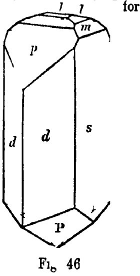


Fig 46

---

[1] As the parts of either half are alternate there still results a symmetrical solid. As either one or other half may be the one thus modified there may result two such symmetric solids which stand in an inverse position to one another. When the modifications affect the upper right hand solid angle the resulting form is called +, when the upper left hand angle it is −.

whilst on the lower end it is bounded by the faces *P* of the primary alone

It has been found that all hemimorphic crystals become electrically polar when heated, that is, exhibit opposite kinds of electricity at opposite ends of the crystal The subject will be more fully considered under the electricity of minerals

Hemihedral forms The hemihedral forms of the cubic system are the following —

1 The tetrahedron (fig 47), hemihedral of the octahedron, is bounded by four equilateral triangles It has six equal edges with faces meeting at 70° 32, and four trigonal angles The principal axes join the middle points of each two opposite edges Examples fahlore, boracite, and helvine

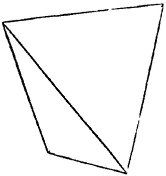


Fig 47

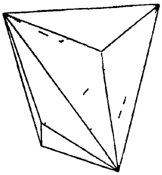


Fig 48

2 The trigonal dodecahedrons (fig 48), hemihedral of the icositetrahedron, are bounded by twelve isosceles triangles, and vary in general form from the tetrahedron to the cube There are six longer edges corresponding to those of the inscribed tetrahedron, and twelve shorter, placed three and three over each of its faces and four hexagonal and four trigonal angles Example tetrahedrite

3 The deltoid dodecahedrons (fig 49), hemihedral of the triakis octahedron, are bounded by twelve deltoids, and vary in general form from the tetrahedron on the one hand to the rhombic dodecahedron on the other They have twelve longer edges lying in pairs over the edges of the inscribed tetrahedron, and twelve shorter edges, three and three over each of its faces There are six tetragonal (rhombic), four acute trigonal, and four obtuse trigonal angles The principal axes join, two and two, opposite rhombic angles Example tetrahedrite

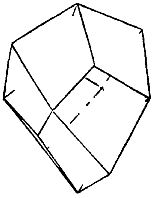


Fig 49

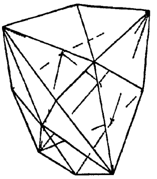


Fig 50

4 The hexakistetrahedrons (fig 50), hemihedral of the hexakis octahedron, are bounded by twenty four scalene triangles, and most commonly have their faces grouped in four systems of six each The edges are twelve shorter and twelve longer, lying in groups of three over each face of the inscribed tetrahedron, and twelve intermediate in pairs over its edges The angles are six rhombic, joined in pairs by the principal axes, and four acuter and four obtuser hexagonal angles Example diamond

In these forms, often named "tetrahedral, the faces are oblique to each other Their derivation and signs are as follows The tetrahedron arises when four alternate faces of the octahedron two opposite above and two intermediate below, are enlarged so as to obliterate the other four, and its sign is hence $\frac{O}{2}$ But, as either four faces may be thus enlarged or obliterated two tetrahedrons can be formed, similar in all respects except in position, and together making up the octahedron These are distinguished by the signs + and −, added to the above symbol, but only the latter in general expressed, thus $-\frac{O}{2}$ In all hemihedric systems two forms similarly related occur, which may thus be named complementary forms The trigonal dodecahedron is derived from the icositetrahedron by the expansion of the alternate trigonal groups of faces Its sign is $-\frac{mOm}{2}$, the most common variety being $\frac{2O2}{2}$ The deltoid dodecahedron is in like manner the result of the increase of the alternate trigonal groups of faces of the triakisoctahedron, and its sign is $\frac{mO}{2}$ Lastly, the hexakistetrahedron arises in the development of alternate hexagonal groups of faces in the hexakisoctahedron, and its sign is $\frac{mOn}{2}$

Two semitesseral forms with parallel faces occur (1) The pentagonal dodecahedrons (fig 51), bounded by twelve *symmetrical* pentagons, vary in general aspect between the cube and the rhombic dodecahedron They have six regular (and in general longer) edges, lying over the faces of the inscribed cube, and twenty four, generally shorter (seldom longer), edges, usually lying in pairs over its edges The solid angles are eight of three equal interfacial angles, and twelve of three interfacial angles, of which only two are equal Each principal axis unites two opposite regular edges. This form is derived from the tetrakishexahedron, and its sign is $\frac{\infty On}{2}$. It is found frequently in iron pyrites and cobaltine

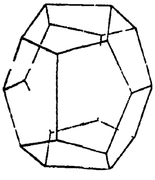


Fig 51

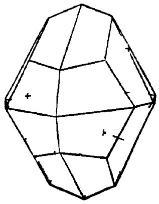


Fig 52

(2) The dyakisdodecahedron (fig 52), bounded by twenty four trapezoids with two sides equal, has twelve short, twelve long and twenty four intermediate edges The angles are six equiangular rhombic, united in pairs by the principal axes, eight trigonal, and twenty four irregular tetragonal angles It is derived from the hexakisoctahedron, and its sign is $\left[\frac{mOn}{2}\right]$ the brackets being used to distinguish it from the hexakistetrahedron, also derived from the same primary form It occurs in iron pyrites and cobaltine The two other semitesseral forms, the pentagonal dodecahedron (fig 53), and the pentagonal icositetrahedron (fig 54), both bounded by *irregular* pentagons, have not yet been observed in nature

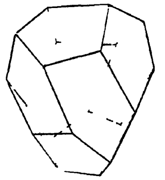


Fig 53

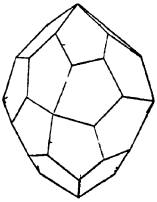


Fig 54

Combinations —The above mentioned forms of the tesseral system (and this is true also of the five other systems of crystallization) not only occur singly, but often two, three, or more occur united in the same crystal, forming what are named combinations Combinations

In this case it is evident that no one of the individual forms can be complete, because the faces of one form must interfere with, by diminishing, the faces of other forms A combination therefore implies that the faces of one form shall appear symmetrically disposed between the faces of other forms, and consequently take the place of certain of their edges and angles These edges and angles are thus, as it were, cut off, and a greater number of new ones produced in their place, which properly belong neither to the one form nor the other, but are angles of combination These new faces are hence termed modifications, and the original or primary or simple form is said to be modified Usually one form predominates more than the others, or has more influence on the general aspect of the crystal, and hence is distinguished as the predominant form, the others being considered subordinate

The sign of the combination consists of those of its constituent forms, written in the order of their influence or importance in the combination, with a point between each pair

It will be readily seen that such combinations may be exceedingly numerous, or rather infinite and only a few of the more common can be noticed Many others more complicated will occur in the descriptive part of this article Among holohedral combinations, the cube octahedron and rhombic dodecahedron are the predominant forms In fig 27 the cube has its angles replaced by the faces of the octahedron which truncate the angles and the sign of this combination is $\infty O \infty$ O In fig 28 this process may be regarded as having proceeded still farther so that the faces of the octahedron nearly equal those of the cube while in fig 29 they now predominate the sign still of the same two elements but in reverse order is O $\infty O \infty$ It will thus be seen that through an increase in the amount of the abstraction of the faces of the cube the figure gradually passes over into that of the octahedron This may occur in all cases and is termed the passage of the cube into the octahedron (or *vice versa*) or a transition by decrement

In fig 31 the cube has its edges replaced by the faces of the rhombic dodecahedron which truncate the edges the sign being $\infty O \infty$ ∞O while in fig 32 there is the same combination but with the faces of the cube subordinate and hence the sign is ∞O $\infty O \infty$ The former figure it will be seen has more the general aspect of the cube the latter of the dodecahedron Here the solid angles of the latter are truncated by the faces of the cube and we have the passage of the cube into the dodecahedron by decrement The same transition through truncation or decrement could be shown in all series of combinations and in both directions the last stage of the passage into one or other form always consisting of the replacement of its solid or interfacial angles by faces of the departing figure more or less minute A few illustrations of this may be given in the three most important forms

The relationship of the tetrakishexahedron to the cube has above been stated to be that its faces form six low quadrilateral pyramids which rest upon or spring from the edges of the cube (From this the form derives its trivial name of four faced cube) Hence these faces bevel the edges of the cube The first stage of such bevelling (or the last stage of the truncation of the tetrakis hexahedron by the faces of the cube—whichever way it may be regarded) is seen in fig 55 As the cubic face is here dominant the sign is $\infty O \infty$ ∞O_2 Fig 56 shows a somewhat similar stage in the modification produced through the combination of the icositetrahedron with the cube The trilateral pyramid which this form places upon the faces of the cube rests upon its solid angles, instead of as in the last case upon its edges hence it is these solid angles which in the process of decrement it replaces by faces which form a low three sided pyramid The triakisoctahedron again modifies the solid angles of the cube as shown in fig 57 by a low three sided pyramid positioned at right angles to that considered in the last combination As the hexakisoctahedron is merely the two faced form of that last considered the pyramid which modifies the solid angles is in its combination with the cube six sided as in fig 58

Fig 55

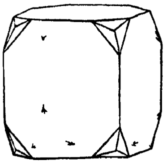


Fig 56

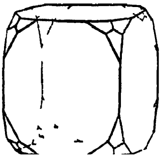


Fig 57

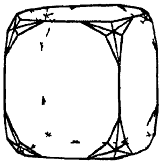


Fig 58

As the faces of the rhombic dodecahedron truncate the edges of the octahedron fig 34 represents the first stage of such truncation or combination while fig 35 may be taken as representing the last the faces of the octahedron being there nearly totally removed

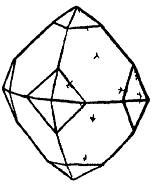


Fig 59

Fig 59 shows the first stage of the passage of the octahedron into the icositetrahedron in the truncation of the solid angles of the former form by a four sided pyramid formed by the (6 × 4) faces of the latter The faces of the octahedron truncate the three faced solid angles of the rhombic dodecahedron Fig 35 shows the first stage of this truncation, while fig 34 shows an advanced amount The faces of the icositetrahedron truncate the edges of the rhombic dodecahedron, as in fig 60 while those of the latter truncate the unequal angled tetragonal (or rhombic) angles of the former (fig 61) The faces of the hexakisoctahedron bevel the edges of the rhombic dodecahedron

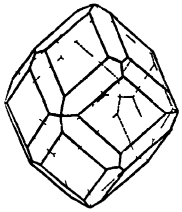


Fig 60

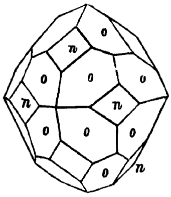


Fig 61

While such transitions may appear indefinite yet certain minerals have either in themselves a habit or have at certain localities a habit of crystallizing so markedly *in a certain stage* of these transitions as to be absolutely capable of recognition thereby

Combinations of hemihedral or as they have been called semi tesseral forms are of three classes —those with holohedral forms, those in which the faces fall obliquely on one another and those with parallel faces Fig 62 shows the combination of a right handed tetrahedron with the cube which truncates its edges the tetrahedron here being dominant Fig 63 again shows a combination of the cubo dodecahedron with a right handed tetrahedron, the first or holohedral form being in this case markedly dominant

Combinations of hemi hedral forms

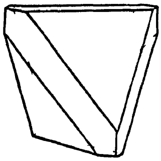


Fig 62

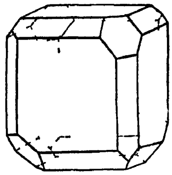


Fig 63

Fig 64 is an illustration of the second class combinations of oblique faced semitesseral forms with each other In it a right handed tetrahedron has its solid angles truncated by the faces of one which is left handed and so its sign is $\frac{O}{2}, -\frac{O}{2}$ Fig 65 shows a combination of a right handed tetrahedron with a left-handed three faced tetrahedron Fig 66 shows a combination of a right-handed hemihedron of the icositetrahedron with a right-handed tetrahedron

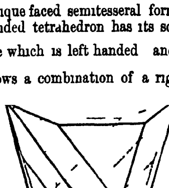


Fig 64

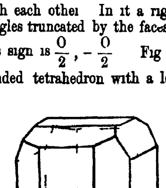


Fig 65

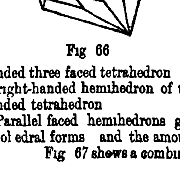


Fig 66

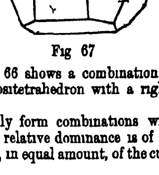


Fig 67

Parallel faced hemihedrons generally form combinations with holohedral forms and the amount of relative dominance is of all Fig 67 shows a combination, in equal amount, of the cube with a vertical faced pentagonal dodecahedron while fig 68 shows an increase in the amount of truncation effected by the latter Fig 69 shows the combination of the cube with the dyakidodecahedron, the former being dominant In fig 70 an octahedron in dominance is combined with the vertical faced pentagonal dodecahedron in fig 71 the faces of these forms are of nearly equal size, while in fig 72 the octahedral faces are nearly removed The solid angles of the octahedron are modified in fig 73 by the faces of the dyakis dodecahedron In fig 68 a vertical faced pentagonal dodecahedron is the prevailing form in combination with the cube while in fig 74 the faces of the octahedron are superadded In fig 75 its octahedral angles are modified by the faces of the icositetrahedron and in fig 76 by those of the octahedron in addition In fig 77 they are modified by the faces of the dyakisdodecahedron

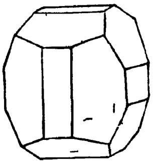


Fig 68

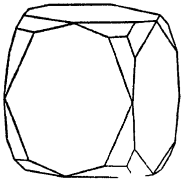


Fig 69

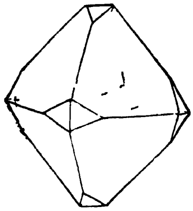


Fig 70

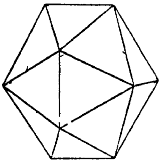


Fig 71

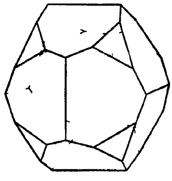


Fig 72

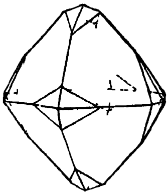


Fig 73

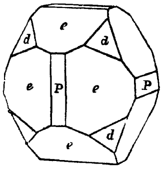


Fig 74

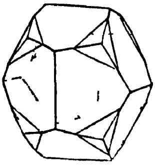


Fig 75

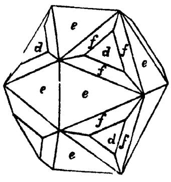


Fig 76

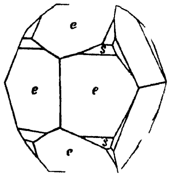


Fig 77

In each of the five systems which follow there is this difference from the cubic system that one axis is always unequal to (longer or shorter than) the others This is placed erect, and named the chief axis, its ends are poles, and the edges connected with them polar edges The other axes are named subordinate or lateral axes, and the plane that passes through them is the base A plane through the chief and a lateral axis is a normal chief section In these systems also occur the three forms of “pyramids, ‘prisms,’ and “pinacoids’ (1) The pyramids have their faces triangles Pyramids in crystallography are each composed of two geometric pyramids placed base to base, and named “closed forms, as the crystals are shut in by definite faces on every side (2) The prisms are bounded by plane faces parallel to one axis They are thus of unlimited extent in the direction of that axis, and therefore named open forms, but in solid crystals are shut in by faces of other forms (3) The pinacoids, or tables, have two faces intersecting one axis and parallel to the others, and thus are also open forms, or unlimited in the direction of these axes Forms (2) and (3), when conjoined mutually shut in each other, or produce closed forms

Pyramidal system

II *Pyramidal or Tetragonal System* —This system has three axes at right angles, two of them equal, and the chief axis longer or shorter The name tetragonal is derived from the form of the base, which is usually quadrangular

There are eight tetragonal forms of which five are closed 1) Tetragonal pyramids figs 78 79) are enclosed by eight isosceles triangles with four middle edges all in one plane and eight polar edges There are three kinds of this form, distinguished by the position of the lateral axes In the first these axes unite the opposite angles in the second they intersect the middle edges equally and in the third they lie in an intermediate position or divide these edges unequally — the last being hemihedral forms These pyramids are also distinguished as obtuse (fig 78) or acute (fig 79) according as the vertical angle is greater or less than in the regular octahedron (2) Ditetragonal pyramids (fig 80) are bounded by sixteen scalene triangles whose base lines are all in one plane This form rarely occurs except in combinations (3) Tetragonal sphenoids (fig 81), bounded by four isosceles triangles, are the hemihedral forms of the first variety of tetragonal pyramids (4) The tetragonal scalenohedron (fig 82), bounded by eight scalene triangles, whose bases rise and fall in a zigzag line is the hemihedral form of the ditetragonal pyramid Nos (3) and (4) are rare (5) The tetragonal trapezohedron is not found in minerals as a simple form The three open forms are—(1) tetragonal prisms bounded by four planes parallel to the principal axis which may be either longer (fig 83) or shorter (fig 84) than the lateral axes (2) ditetragonal prisms bounded by eight similar planes and (3) the basal pinacoid, consisting merely of two parallel faces bounding the prisms at the ends, above and below

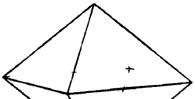


Fig 78

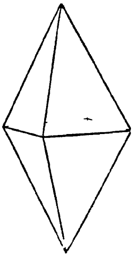


Fig 79

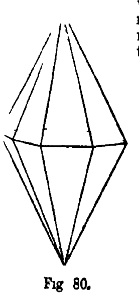


Fig 80

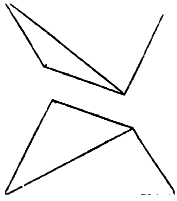


Fig 81

The various series of tetragonal crystals are distinguished from each other only by their relative dimensions To determine these,

Primitive pyramid. one of the series must be chosen as the primary form and for this purpose a tetragonal pyramid of the first variety designated by P as its sign is selected The angle of one of its edges especially the middle edge found by measurement determines its angular dimensions whilst the proportion of the principal axis a to the

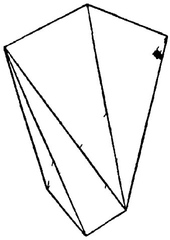


Fig 82

Fig 83

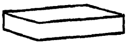


Fig 84

lateral axes supposed equal to 1 gives its linear dimensions The parameters therefore of each face of the fundamental form are 1 1 a

Now if n be any (rational) number either less or greater than unity and if from any distance ma in the principal axis planes be drawn to the middle edge of P then new tetragonal pyramids of the first order but more or less acute or obtuse than P are formed

Derived pyramids The general sign of these pyramids is mP and the most common varieties $\frac{1}{2}P$ 2P and 3P —with the chief axis half twice or thrice that of P If m becomes infinite then the pyramid

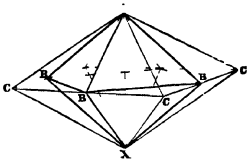


Fig 85

Prism passes into a prism indefinitely extended along the principal axis and with the sign ∞P If m 0 which is the case when the lateral axes are supposed infinite then it becomes a

Pinacoid pinacoid consisting properly of two basal faces open towards the lateral axes and designated by the sign 0P The ditetragonal pyramids are produced by taking in each lateral axis distances n greater than 1 and drawing two planes to these points from each of the intermediate polar edges The parameters of these planes are therefore m 1 n and the general sign of the form mPn the most common values of n being $\frac{3}{2}$ 2 3 and ∞ When n ∞ a tetragonal pyramid of the second order arises designated generally by $mP\infty$ the most common in the mineral kingdom being $P\infty$ and $2P\infty$ The relation of these to pyramids of the first order is shown in fig 85 where ABBBC is the first and ACCCX the second order of pyramid In like manner from the prism ∞P the ditetragonal prisms ∞Pn are derived and finally when $n = \infty$ the tetragonal prism of the second order whose sign is $\infty P\infty$

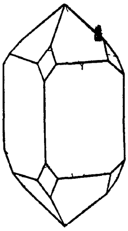


Fig 86

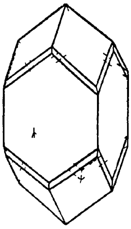


Fig 87

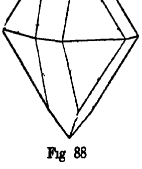


Fig 88

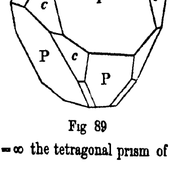


Fig 89

The combinations of the tetragonal system are either holohedral or hemihedral but the latter are rare Prisms and pinacoids must always be terminated on the open sides by other forms Thus in fig 86 a square prism of the first order is terminated by the primary pyramid and has its lateral angles again replaced by another more acute pyramid of the second order so that its sign is ∞P P $2P\infty$

In fig 87 a prism of the second order is first bounded by the fundamental pyramid and then has its edges of combination replaced by a ditetragonal pyramid its sign is $\infty P\infty$ P 3P3 In fig 88 the polar edges of the pyramid are replaced by another pyramid its sign being P $P\infty$ In fig 89 a hemihedric form very characteristic of chalcopyrite is represented —P and P being the two sphenoids a the basal pinacoid and b c two ditetragonal pyramids

Hexagonal system. III *The Hexagonal System* —The essential character of this system is that it has four axes,—three equal lateral axes intersecting each other in one plane at 60 , and one principal axis at right angles to these The plane through the lateral axes, or the base from its hexagonal form, gives the name to the system As in the last system, its forms are either closed or open They are divided into holohedral, hemihedral and tetartohedral —the last which are rare, having only a fourth part of the faces developed Only a few of the more common forms require to be here described

Pyramids. The hexagonal pyramids (figs 90 91) are bounded by twelve isosceles triangles and are of three kinds according as the lateral axes fall in the angles in the middle of the lateral edges or in another point of these edges the last being hemihedral forms They are also classed as acute or obtuse but without any precise limits The trigonal pyramid is bounded by six triangles and may be viewed as the hemihedral form of the hexagonal The dihexagonal pyramid is bounded by twenty four scalene triangles but has never been observed alone and rarely even in combinations The more common prisms are the hexagonal of six sides in these the vertical axis may be either longer than the lateral as in fig 92 or shorter as in fig 93 There are also dihexagonal of twelve sides

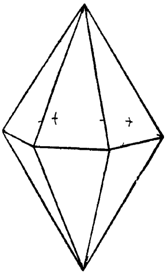


Fig 90

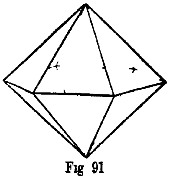


Fig 91

A particular pyramid P is chosen as the fundamental form of this system and its dimensions determined either from the proportion of the lateral to the principal axis (1 a) or from the measurement of its angles From this form (mP) others are derived exactly as in the tetragonal system Thus dihexagonal pyramids are produced with the general sign mPn the chief peculiarity being that whereas in the tetragonal system n might have any rational value from 1 to ∞ in the hexagonal system it can only vary from 1 to 2 in consequence of the geometric character of the figure When n 2 the dihexagonal changes into an hexagonal pyramid of the second order whose sign is $mP2$ When $m = \infty$ various prisms arise from similar changes in the value of n and when $m = 0$ the basal pinacoid is formed

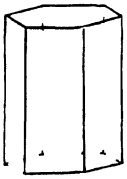


Fig 92

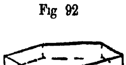


Fig 93

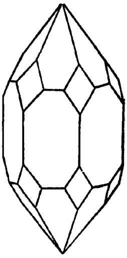


Fig 94

Few hexagonal mineral species form perfect holohedral combinations Though quartz and apatite appear as such yet properly the former is a tetartohedral the latter a hemihedral species In holohedral species the predominant faces are usually those of the hexagonal prisms ∞P (fig 92) and $\infty P2$ or of the pinacoid 0P (fig 93) whilst **Prisms** the pyramids P and 2P2 are the most common subordinate forms Fig 94 represents the prism bounded on the extremities by two pyramids —one P forming the apex, the other 2P2, the rhombic faces on the angles or ∞P P 2P2 Fig 95 is a similar form the upper part of the pyramid being replaced by the pinacoid In some crystals the lateral edges of the prism are replaced by the second prism $\infty P2$ (fig 96) producing an equiangular twelve sided prism which always represents the combination ∞P $\infty P2$ and cannot occur as a simple form Figs 97, 98 are combinations in this system seen in beryl An example of a more complicated combination is seen in fig 99 of a crystal of apatite whose sign with the corresponding letters is $\infty P(M)$ $\infty P2(e$ $0P(P)$ $\frac{1}{2}P(r)$ $P(x)$ $2P(\ )$ $P2(a)$ $2P2(s)$ $4P2(d)$

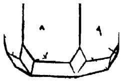


Fig 95

Fig 96

Fig 97

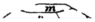


Fig 98

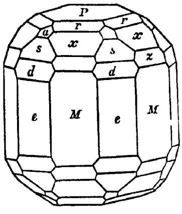


Fig 99

Rhombohedral forms Hexagonal minerals frequently crystallize in those series of hemihedral forms that are named rhombohedral from the prevalence in them of rhombohedrons These (figs 100 101) are bounded by six rhombi whose lateral edges do not lie in one plane but rise and fall in a zigzag manner The principal axis unites the two trigonal angles formed by three equal plane angles and in the most common variety the secondary axes join the middle points of two opposite edges When the polar edges form an angle of more than 90 the rhombohedrons are named obtuse when of less than 90° acute fig 102 represents the first fig 103 the second Hexagonal scalenohedrons (fig 104) are bounded by twelve scalene triangles whose lateral edges do not lie in one plane The principal axis joins the two hexagonal angles and the secondary axis the middle points of two opposite lateral edges

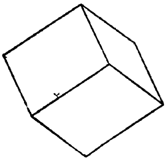


Fig 100

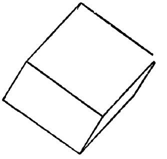


Fig 101

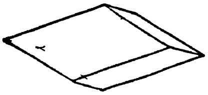


Fig 102

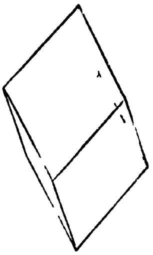


Fig 103

The rhombohedron is derived from the first order of hexagonal pyramid by the hemihedral development of its alternate faces Its general sign should therefore be $\frac{mP}{2}$, but on several grounds it is found better to designate it by R or mR and its complementary figure by $-mR$ When the prism or pinacoid arises as its limiting form, they are designated by ∞R and $0R$ though in no respect changed from the limiting forms ∞P and $0P$ of the pyramid The scalenohedron is properly the hemihedral form of the dihexagonal pyramid but is more easily understood as derived from the inscribed rhombohedron mR If the halves of the principal axis of this be multiplied by a definite number n and then planes be drawn from the extremities of this enlarged axis to the lateral edges of the rhombohedron as in fig 105 the scalenohedron is constructed It is now designated by mRn (the n on the right here referring to the chief axis) and the dihexagonal prism in this series by ∞Rn (formerly mR^n and ∞R^n)

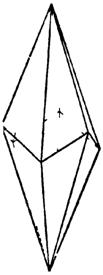


Fig 104

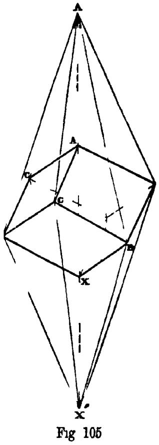


Fig 105

The combinations of rhombohedral forms are very numerous several hundreds having been described in calc spar alone Among the most common is the prism in combination with a rhombohedron as seen in the twin crystal of calc spar (fig 106) with the sign R $\frac{1}{2}R$ the lower half being the same form with the upper but turned round 180 In fig 107 the rhombohedron n R has its polar edges replaced by another rhombohedron $\frac{1}{2}$ R and in fig 108 its lateral edges bevelled by the scalenohedron mRn A more complex combination of five forms is represented in the crystal of calc spar fig 109 its sign with the letters on the faces being $R^5(y)$, $R^3(r)$ $R(P)$ $4R(m)$ $\infty R(c)$ Tetartohedral combinations are seen most distinctly in rock crystal

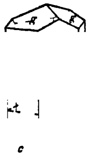


Fig 106

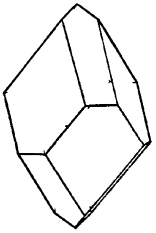


Fig 107

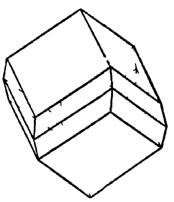


Fig 108

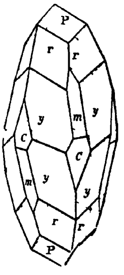


Fig 109

Right prismatic system. IV *Right Prismatic or Rhombic System*—This system is characterized by three unequal axes, all at right angles to each other Any one of these may be assumed as the chief axis, when the others are named subordinate The plane passing through the secondary axes, or the base, forms a rhombus and from this one of its names is derived As prismatic forms are most frequent (the prism standing vertically on the rhombic base), it is best defined as the right prismatic This system comprises only a few varieties of forms that are essentially distinct, and its relations are consequently very simple

There are two closed forms 1) The rhombic pyramids (figs 110, 111), bounded by eight scalene triangles, whose lateral edges lie in one plane, and form a rhombus They have eight polar edges (four acute and four more obtuse) and four lateral edges The angles are six rhombic the most acute at the extremities of the longest axis (2) The rhombic sphenoids (figs 112, 113) are bounded by four scalene triangles with their lateral edges not in one plane, and are hemihedral forms of the rhombic pyramid They are of very infrequent occurrence

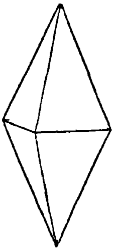


Fig 110

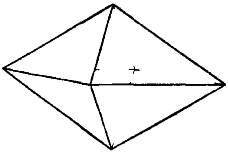


Fig 111

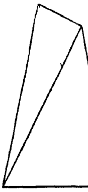


Fig 112

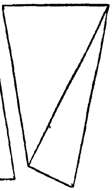


Fig 113

Sphenoids

Prisms The open forms again are rhombic prisms bounded by four planes parallel to one of the axes which is indefinitely extended and may be longer than the lateral as in fig 114 or shorter as in fig 115 They are divided into upright (as in the above figs) and horizontal prisms, according as either the principal or one or other of the lateral axes is supposed to become infinite For the latter form the name doma or dome has been used and two kinds the macrodome (fig 116) and the brachydome (fig 117) have been distinguished

Domes

Fig 114

Pinacoids Rhombic pinacoids also arise when one axis becomes = 0 and the two others are indefinitely extended, and so we have macropinacoids (fig 118) and brachypinacoids (fig 119)—the qualifying term thus designating the axis to which the faces of the dome or pinacoid are parallel

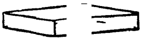


Fig 115

In deriving these forms from a primary, a particular rhombic pyramid P is chosen, and its dimensions determined either from the angular measurement of two of its edges, or by the linear proportion of its axes *a* *b* *c* the greater lateral axis *b* being assumed equal to 1 To the greater lateral axis the name macrodiagonal is given, to the shorter that of brachydiagonal, and the two principal sections are in like manner named macrodiagonal and brachydiagonal, according to the axis they intersect The same terms are applied throughout all the derived forms They consequently mark only the position of the faces in respect to the axes of the fundamental crystal, and frequently of necessity without reference to the relative magnitude of the derived axes.

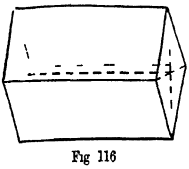


Fig 116

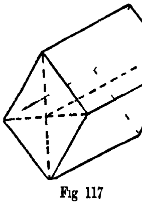


Fig 117

Macro and brachy diagonal

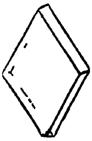


Fig 118

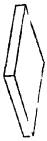


Fig 119.

By multiplying the principal axis by any rational number *m*, greater or less than 1, a series of pyramids arise, whose general sign is *m*P, and their limits are the prism and pinacoid, the whole series being contained in this formula, 0P mP P . mP ∞P,—which is the fundamental series, the lateral axes always remaining unchanged

Derived forms.

From each member a new series may, however, be developed in two directions, by increasing one or other of the lateral axes When the macrodiagonal is thus multiplied by any number *n* greater than 1 and planes drawn from the distance *n* to the polar edges a new pyramid is produced, named a macropyramid, with the sign $m\bar{P}n$ the mark over the P pointing out the axis enlarged When $n = \infty$, a macrodome results, with the sign $m\bar{P}\infty$ If the shorter axis is multiplied, then brachypyramids and brachydomes are produced, with the signs $m\breve{P}n$ and $m\breve{P}\infty$ So also from the prism ∞P, on the one side, originate numerous macroprisms $\infty\bar{P}n$ with the limiting macropinacoid $\infty\bar{P}\infty$, on the other, numerous brachyprisms $\infty\breve{P}n$, with the limit form $\infty\breve{P}\infty$, or the brachypinacoid In figs 120, 121 the two domes are shown in their relation to the primitive pyramid

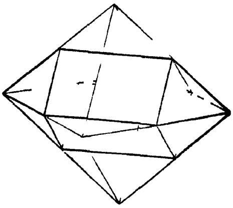


Fig 120

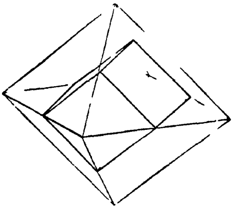


Fig 121

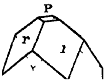


Fig 122

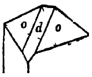


Fig 123

Fig 124

The pyramids seldom occur independent, or even as the predominant forms in a combination, sulphur, however, is an exception Prisms or pinacoids usually give the general character to the crystal, which then appears either in a columnar or tabular or even rectangular pyramidal form The determination of the position of these crystals, as vertical or horizontal, depends on the choice of the chief axis of the fundamental form In the topaz crystal (fig 122) the brachyprism and the pyramid are the predominant elements associated with the prism, its sign and letters being $\infty\breve{P}2(l)$, P(*o*) ∞P(*M*) Fig 123 of stilbite is another example, the macropinacoid $\infty\breve{P}\infty$ or *M* being combined with the pyramid P(*r*), the brachypinacoid $\infty\breve{P}\infty\,(T)$, and the basal pinacoid 0P(*P*) Another instance is fig 124 of a lievrite crystal, where the brachyprism and pyramid combine

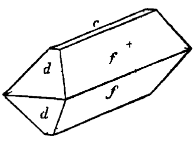


Fig 125

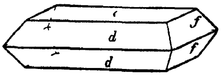


Fig 126

Fig 127

with the macrodome, or $\infty\breve{P}2$, P, $\bar{P}\infty$ The above figures are very common forms of barytes,—figs 125 and 126 being both composed of the pinacoid 0P, a brachydome, and a macrodome, with sign 0P(*c*), $\breve{P}\infty$ (*f*) $\frac{1}{2}\bar{P}\infty$ (*d*) The variation in aspect arises from the predominance of different faces and fig 127 consists of the macrodome $\frac{1}{2}\bar{P}\infty$, the prism ∞P(*g*) and the pinacoid 0P

V *The Oblique Prismatic System* —This system is characterized by three unequal axes, two of which intersect each other at an oblique angle, and are cut by the third at right angles One of the oblique axes is chosen as the chief axis, and the other axes are then distinguished as the orthodiagonal (right angled) and clinodiagonal (oblique angled) The same terms are applied to the chief sections, and the name of the system refers to the fact that these two planes form with the base two right angles and one oblique angle C

The forms of this system approach very near to those of the right prismatic series, but the inclination of the axis even when almost a right angle gives them a peculiar character by which they are always readily distinguished Each pyramid thus separates into two altogether independent forms or hemipyramids

Three varieties of prism also occur—vertical inclined and horizontal—with faces parallel to the chief axis the clinodiagonal or the orthodiagonal The horizontal prisms, like the pyramids separate into two independent partial forms named hemiprisms or hemidomes The inclined prisms are often designated clinodomes the term prism being restricted to the vertical forms Orthopinacoids and clinopinacoids are also distinguished, from their position in relation to the axes The monoclinic pyramids (fig 128) are bounded by eight scalene triangles of two kinds four and four only being similar Their lateral edges lie all in one plane and the similar triangles are placed in pairs on the clinodiagonal polar edges

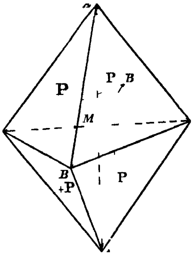


Fig 128

The two pairs in the acute angle between the orthodiagonal and basal sections are designated the positive hemipyramid whilst the two pairs in the obtuse angles of the same sections form together the negative hemipyramid But as these hemipyramids are wholly independent of each other, they are rarely observed combined More frequently each occurs alone, and then forms a prism like figure, with faces parallel to the polar edges, and open at the extremities Hence like all prisms they can only appear in combination with other forms The vertical prisms are bounded by four equal faces parallel to the principal axis and the cross section is a rhombus the clinodomes have a similar form and section, whilst the horizontal prisms or domes have unequal faces, and their section is a rhomboid

The mode of derivation of these forms closely resembles that of the rhombic series A complete double pyramid is assumed as the fundamental form and designated $\pm P$ in order to express the two portions of which it consists Its dimensions are given when the proportion of its axes *a* *b* *c* and the angular inclination of the oblique axes C which is also the inclination of the orthodiagonal section to the base are known

The fundamental series of forms is 0P $\pm mP$ $\pm P$ $\pm mP$ ∞P, from each of whose members, by changing the dimensions of the other axes new forms may be again derived Thus from $\pm mP$, by multiplying the orthodiagonal by any number *n*, a series of orthopyramids $\pm mP^{o}n$ is produced, with the orthodomes $mP^{o}\infty$ as limiting forms The clinodiagonal produces a similar series of clinopyramids $\pm mP^{c}n$, with the limiting clinodome $mP^{c}\infty$ always completely formed, and therefore without the signs ± attached From ∞P arise orthoprisms $\infty P^{o}n$ and the orthopinacoid $\infty P^{o}\infty$, and clinoprisms $\infty P^{c}n$ and the clinopinacoid $\infty P^{c}\infty$ In these signs the *o* or *c* attached to the P indicates that the orthodiagonal (*o*) or clinodiagonal (*c*) axis has been multiplied Formerly the latter forms were enclosed in brackets, thus $(mP\infty)$ $-mP\infty$

The combinations of this system may be easily understood from their resemblance to those of the right prismatic the chief difficulty being in the occurrence of *partial* forms, which, however, closely resemble the hemihedral forms of the previous systems A few examples only need therefore be given

Fig 129 represents a very common form of gypsum crystals, $\infty P^{c}\infty$, (*P*), ∞P(*f*), P(*l*) The most common form of augite is represented in fig 130, with the sign ∞P(*M*), $\infty P^{o}\infty$ (*r*), $\infty P^{c}\infty$ (*l*), P(*s*)

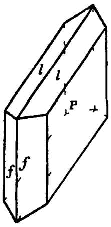


Fig 129

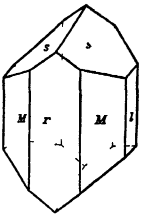


Fig 130

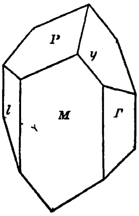


Fig 131

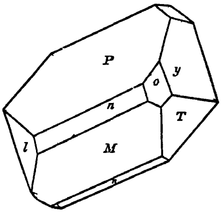


Fig 132

Fig 131 is a crystal of common felspar or orthoclase, composed of the clinopinacoid $\infty P^{c}\infty$ (*M*) the prism ∞P(*T*), the basal pinacoid 0P(*P*), and the hemidomes $2P^{o}\infty$ (*y*) to which, in fig 132 of the same mineral the hemipyramid P(*o*) and the clinodome $2P^{c}\infty$ (*n*) are added

VI *Anorthic or Triclinic System* —This is the least regular system, and departs the most widely, indeed almost absolutely, from symmetry of form The axes are all unequal, and inclined at angles none of which are right angles,—so that, to determine any crystal, or series of forms, the proportion of the axes *a* *b* *c*, and also their angles, or those of the inclination of the chief sections, must be known As in the previous systems, one axis is chosen as the principal axis, and the two others distinguished as the macrodiagonal and brachydiagonal axes In consequence of the oblique position of the principal sections, this system consists entirely of partial forms wholly independent of each other, and each composed only of two parallel faces The complete pyramid is thus broken up into four distinct quarter pyramids, and the prism into two hemiprisms Each of these partial forms is thus nothing more than a pair of parallel planes, and the various forms consequently mere individual faces This circumstance renders many triclinic crystals very unsymmetrical in appearance

Triclinic pyramids (fig 133) are bounded by eight triangles whose lateral edges lie in one plane They are equal and parallel two and two to each other, each pair forming as just stated a tetartopyramid or open form, only limited by combination with other forms or as we may suppose, by the chief sections The prisms are again either vertical or inclined, the latter are named domes, and their section is always rhomboidal In deriving the forms the fundamental pyramid is placed upright with its brachydiagonal axis to the spectator, and the partial forms designated, the two upper by P and P, the two lower by P and P as in the figure The further derivation now follows as in the right prismatic system, with the modifications already mentioned

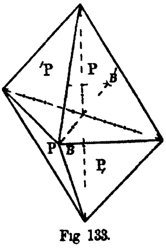


Fig 133

Some combinations of this system, as the series exhibited by most of the felspars, approach very near to the oblique prismatic system, whilst others, as cyanose and axinite show great incompleteness and want of symmetry In the latter case the determination of the forms is often difficult In the albite crystal (figs 134, 135) *P* is the basal pinacoid 0P, *M* the brachydiagonal pinacoid ∞P̆∞ *s* the upper right pyramid P′, *l* the right hemiprism ∞P , *T* the left hemiprism ∞ P, and *x* the hemidome ′P̆ ∞ Figs 136 and 137 are crystals of axinite, the former from Dauphine, the latter from Cornwall, of whose faces the following is the development - the macropinacoid ∞P̄∞ *P* the left hemiprism ∞ P *u* the left upper quarter pyramid P *l* the left upper quarter pyramid 2 P, *s* the left upper partial form of the macropyramid 3 P̄3, and *x* the hemidome 2 P ∞

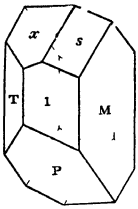


Fig 134

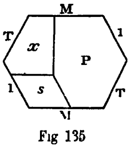


Fig 135

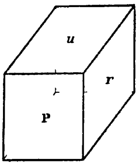


Fig 136

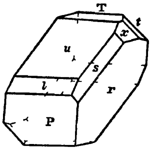


Fig 137

The Measurement of the Angles of Crystals

The permanence of the angular dimensions of crystals shows the importance of some accurate method of measuring their angles,—that is, the inclination of two faces to each other Instruments for this purpose are called goniometers

Two have been specially used for this purpose—the common or contact goniometer invented by Carangeau, and the reflecting goniometer of Wollaston The former is simply two brass rulers turning on a common centre between which the crystal is so placed that its faces coincide with the edges of the rulers, and the angle is then measured on a graduated arc This instrument is sufficiently accurate for many purposes and for large crystals, but for precise determination is far inferior to the reflecting goniometer This requires smooth and even faces, but these may be very small, even the hundredth of an inch and, as small crystals are generally the most perfect, far greater accuracy can be attained

The reflecting goniometer is represented in fig 138 It consists essentially of a graduated circle *mm* divided on its edge into twice 180°, or more frequently into half degrees, the minutes being read off by the vernier *hh* This circle turns on an axis connected with *tt*, so that by turning this the circle is moved round, but it is stopped at 180°, when moving in one direction, by a spring at *k* The other part of the instrument is intended to attach and adjust the crystal to be measured The first axis of *mm* is hollow, and a second axis *aa* passes through it from *ss* so that this and all the connected parts from *b* to *f* can be turned without moving the circle *mm* The axis *d* passes through a hole in *bc*, so that it can turn the arm *dc* into any required position, *f* is a similar axis turning the arm *og* and *pq* a fourth axis, in like manner movable in *q* and with a small knob at *q* to which the crystal to be measured is attached

When about to be used the instrument should be placed on a table, with its base horizontal (which is readily done by the screws in it), and opposite to a window at about 12 or 15 feet distance, so that its axis shall be parallel to the horizontal bars of the window One of the upper bars of the window, and also the lower bar, or, instead of the latter, a white line on the floor or table parallel to the window, should then be chosen, in order to adjust the crystal The observer places himself behind the instrument with the side *a* at his right hand. The crystal is then attached to *q* by a piece of wax, with the two faces to be measured upwards, and the edge of union of the faces, including the angle to be measured, as nearly as possible in the line of *aa* The eye being brought near to the first face of the crystal, the axes *aa* and *p* are turned till the image of the window is seen reflected in the face with the horizontal and vertical bars in their position The axis *d* is then turned through a considerable angle (say 60°), and the image of the window again sought and brought into its proper place by turning the axis *f*, without moving *p* When this is done that face is brought into its true position, normal to *d*, so that no motion of *d* can disarrange it Hence the image of the window may now be sought in the second face, and brought into its true position, with the horizontal bars seen horizontal, by moving the axes *d* and *a* When this is done the crystal is properly "adjusted" The angle is measured in the following manner First bring the zero of the circle and vernier to coincide, and then turn the inner axis *a* or *ss*, and move the eye till the image of the upper bar of the window reflected from the more distant face of the crystal coincides with the lower bar or horizontal line seen directly Keeping the eye in its place, turn the other axis *tt* till the reflected image of the upper bar in the other face in like manner coincides with the lower line the angle of the two faces is then read off on the divided circle As the angle measured is not directly that of the faces but of the rays of light reflected from them, or the difference between the angle wanted and 180°, the circle has the degrees numbered in the reverse direction, so as to give the angle without the trouble of subtracting the one from the other

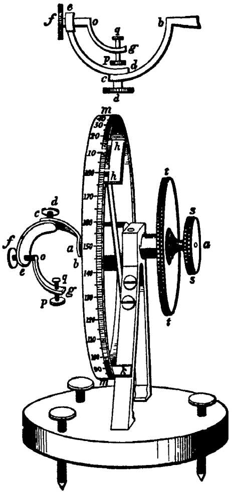


Fig 138

The apparatus figured is for adjusting the crystal, and is an improvement suggested by Naumann In the original instrument the

moving the plate, or the axis *fo*, and by slight motion of the arm *de*, which should be at right angles nearly to *bc* when used A very marked improvement is to have a small mirror fixed on the stand below the crystal, with its face parallel to the axis *aa*, and inclined at 45° to the window, when the lower line can be dispensed with, and the instrument used for various other purposes of angular measurement Many more perfect instruments have been introduced for the purpose of insuring greater accuracy, but the simple instrument is sufficient for all purposes of determinative mineralogy, and the error from the instrument will, in most cases, be less than the actual variations in the angles of the crystals

Departure from Geometric Simplicity and Loss of Regularity in Crystals

Such departures may be regulated by law, or may result from an undue operation of the force of accretion in certain directions

1 *Regular Departures from Simplicity* —There are three varieties of this —parallel groupings, twin forms, hemitrope forms

Parallel Groupings —A plurality of individuals are here arranged either so that a line which joins their centres becomes a prolongation of one or other of their crystallographic axes, or so that their axes are parallel

Fig 20 shows the first, where cohesion sufficient for stability requires that the minute octahedra must mutually penetrate somewhat into each other Fig 139 shows the same in baryte. If we suppose octahedra united, the upper left hand face of the one with the lower right-hand face of the other, there would be parallelism of their axes Re entering angles would, in such cases, prove a plurality of individuals, but if a number of cubes were superimposed in similar position, no such angles would occur, an elongated square prism resulting, and such arrangements, if

repeated, are linear, or, with diminishing size in the individual, acicular

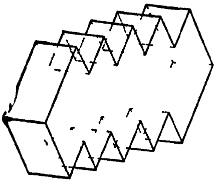


Fig 139

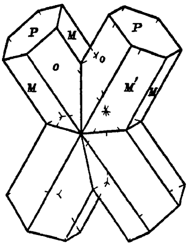


Fig 140

Twins and Hemitropes —Though closely related formed under the operation of very similar laws, and to a certain extent passing into one another, these are not the same In the first case a plurality of individuals must be present, in the second this is not necessary In fig 140 two individuals evidently intersect one another, in figs 141, 142 one individual may be supposed to have been bisected in a certain direction, and the two halves reattached, but in a position differing in some definite manner from their relative position before the separation

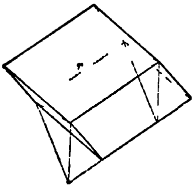


Fig 141

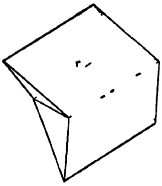


Fig 142

Varieties of twins

There are four varieties of true twins those of apposition, of intersection of partial or completed interpenetration and of corporation

The first is exemplified by spinel, as in fig 143 the second by

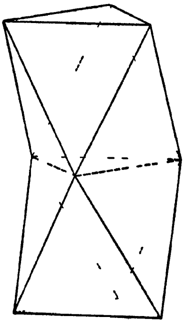


Fig 143

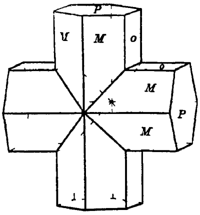


Fig 144

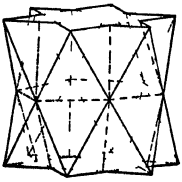


Fig 145

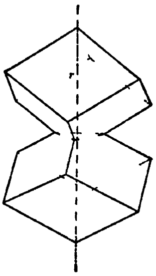


Fig 146

staurolite, as in fig 144, the third by calcite, as in fig 146, and by blende, as in fig 145, where the two individuals of fig 143 may be supposed to have been forced vertically into one another, and the last by quartz, as in fig 147

The following are the laws of union of twins 1 The face of union of twins, termed the "face of composition, must be either a plane which does occur in the mineral twinned, or which can occur in accordance with the fifth law of symmetry A face of

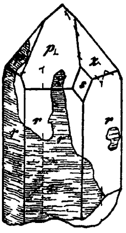


Fig 147

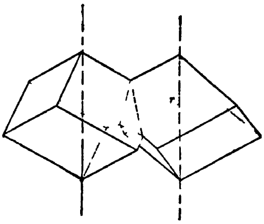


Fig 148

union in twins is also a face of union in hemitropes of the same mineral 2 From the above it results that the axes of the united crystals are either parallel (fig 148) or inclined (fig 149) The former generally occur among hemihedric forms and the two crystals are combined in the exact position in which they would be derived from or would reproduce the primary holohedral form The class with oblique axes occur both in holohedric and in hemihedric forms and the two individuals are then placed in perfect symmetry in accordance with law 1

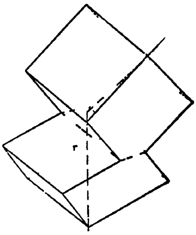


Fig 149

Twins are generally recognized by having re entering angles (figs 150 151) but sometimes the crossed faces coincide in one plane when the combination appears as a single individual (figs 152 153) The line of union may then be imperceptible or it may be disclosed by the intersection of two sets of striæ (figs 154 155) or by some physical diversity in the characters of the two faces

The formation of twin crystals may be again or many times, repeated —forming groups of three four twenty four or more When the faces of union are parallel to each other the crystals form rows of indeterminate extent When they are not parallel, they may return into each other in circles, as in rutile or form bouquet or rosette groups as in chrysoberyl (fig 156 or stellate groups, as in calcite (fig 157) and in cerussite (figs 158 159)

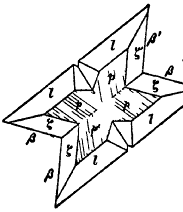


Fig 150

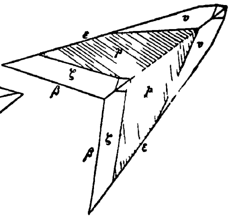


Fig 151

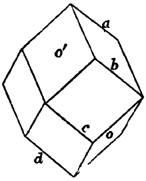


Fig 152

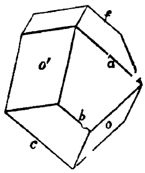


Fig 153

When the crystals are of different size, greater complexity results; but a number of minute crystals are frequently arranged upon a larger at those points where the angles of a single large crystal would protrude Occasionally a simple form is twinned with a more complex one, as in chabasite (fig 160)

Hemitrope crystals we may imagine as having been formed from a single crystal, which has been cut into two halves in a particular direction, and one half turned round 180°, or 90°, or 60° The line about which the revolution is supposed to take place is called the "axis of revolution From the amount of turn usually being 180°, Haüy gave the name hemitrope The position of the two halves in this case resembles that of an object and its image in a mirror, whose surface then would represent the plane of reunion

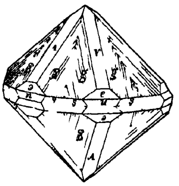


Fig 154

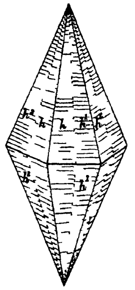


Fig 155

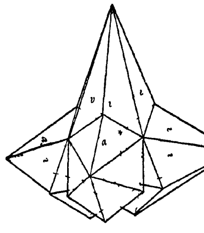


Fig 157

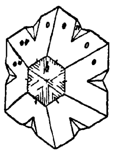


Fig 156

Laws of hemitropism The following are the laws of hemitropes The axis of revolution is always a possible crystallographic line,—either an axis a line parallel to an axis, or a normal to a possible crystalline plane The plane normal to the axis of revolution is called the twin plane, it is either an occurring or a possible plane, and usually one of the more frequently recurring planes Both the axis and the twin plane bear the same relation to both halves of the crystal in their reversed positions consequently the parts of hemitrope crystals are symmetrical with reference to the twin plane (except in triclinic forms and some hemihedral crystals) The face of composition very frequently coincides with the twin plane when not coinciding, the twin plane and the face of composition are generally at right angles to each other, so that the composition face is parallel to the axis of revolution But in twins of incorporation the surfaces of composition have exercised a disturbing influence on one another, so that the surface of union is exceedingly irregular Still in these cases the axis and the plane of twinning retain a definite position, but the face of composition, being no longer defined, is useless as a determinant

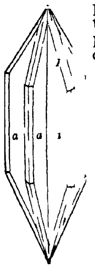


Fig 158

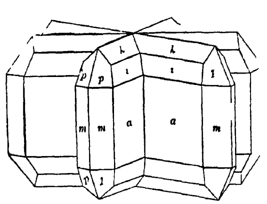


Fig 159

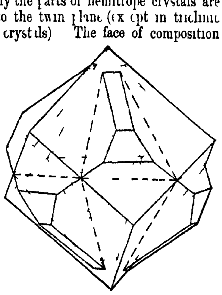


Fig 160

Modes of union There are three modes in which the composition may take place in hemitropes These may be explained by dividing a crystal into halves, with the plane of division vertical, and then turning one of the halves round.

1 One of the halves may be inverted, as if by revolution through 180° on a horizontal axis *at right angles to the plane of section*, and the two faces again united by the surfaces which were separated Here the surfaces of union are the original ones, but the base of one of the halves has taken the place of its summit Examples selenite (fig 161) and orthoclase

2 One of the halves may be turned round through 180°, as if by revolution on *a horizontal axis parallel to the plane of section*, and the face opposite and parallel to that of the plane of section—an originally external face—may then be applied to the other half Here not only has the base of one half become a summit, but a lateral and external face of the original crystal has been thrust to its centre so as to become a face of internal union Example labradorite (fig 162)

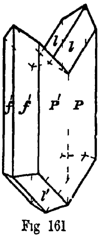


Fig 161

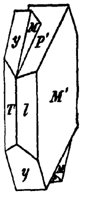


Fig 162

3 One of the halves may be turned round through 180°, as if by revolution *on a vertical axis*, parallel to the plane of section, the external face opposite and parallel to the plane of section becoming a face of union Here, however, both the original summits retain their position as summits Example orthoclase

The first of these modes of composition may occur in each of the systems, but it is not always apparent until disclosed by optical properties The second is rare, and the third still more so

In hemitrope crystals (less frequently in true twins) the halves of the crystal are frequently reduced in thickness in the direction of the ordinary twin axis, and when there is a parallel repetition of hemitropes, which frequently occurs, they are often reduced to very thin plates, not the thickness of paper, giving to the surface of the aggregate a striated structure and appearance

Twins of cubic system. In the *cubic system* the faces of composition, both of twinning and of hemitropic revolution, are those of the cube, the dodecahedron, and the octahedron

In the first case we have the axes of the two crystals necessarily in some cases parallel, or, more correctly falling into one, but as in this system all the axes are alike or all the cubic faces similar, composition may occur along or parallel to all alike, and double or triple twins occur We have examples in twins of the pentagonal dodecahedron (fig 163) made up by the interpenetration of a right and a left (+ and −), and of the tetrahedron, as seen in pyrite and fahlerz respectively In virtue of the position required by law 2 it will be seen that the portion of the solid which is common to both intersecting crystals is in the twin of pyrite the four faced cube, which is the holohedral form of the pentagonal dodecahedron, while in the case of the fahlerz twin (fig 164) the common portion is an octahedron, the holohedral form of the tetrahedron

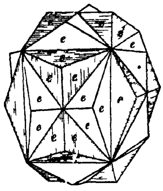


Fig 163

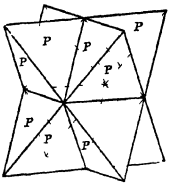


Fig 164

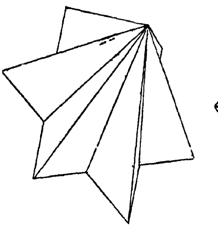


Fig 165

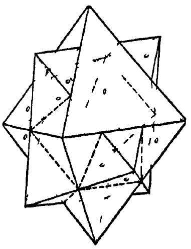


Fig 166

Twinning on an octahedral face is seen in the apposition twin of spinel (fig 143), the tetrahedral twin of blende (fig 165), the interpenetrative octahedral twin of blende seen in fig 166, and the intersecting cubes of fluor (fig 167)

This is also the usual twin face for hemitropes of the cubic system.

It is seen in fig 168 of blende where the two parts of the rhombic dodecahedron are united by it Magnetite, spinel, and diamond frequently occur in octahedral hemitropes of the same composition (fig 169)

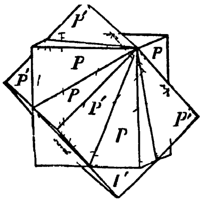


Fig 167

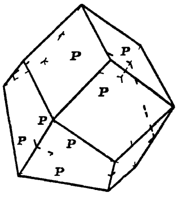


Fig 168

This is also the face of composition for tetartohedral hemitropes Fig 170 is that of the diamond Here six of the faces of the six faced octahedron, with six faces diagonally opposite form a low double six sided pyramid (a portion of an octahedral face truncating each) through an 180 revolution of one set of these Garnet sometimes shows both twins and hemitropes of the dodecahedron, of dodecahedral composition

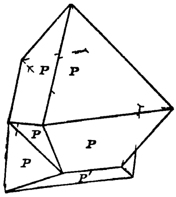


Fig 169

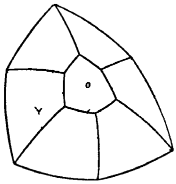


Fig 170

In the *tetragonal system* twin crystals are very uncommon but hemitropes frequent With parallel axes they very seldom occur but are seen in chalcopyrite When the axes are inclined the plane of union is usually one of the faces of the primary pyramid and as these faces are all similar composition may take place simultaneously parallel to all Very complicated forms hence result as seen in chalcopyrite and in cassiterite (fig 171)

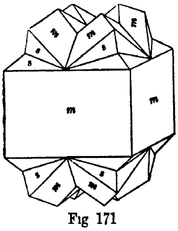


Fig 171

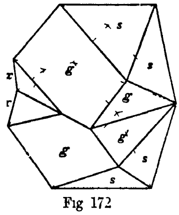


Fig 172

In cassiterite the plane of union is frequently one of the faces of the pyramid $P\infty$ sometimes one of those faces that replace the polar edges of P (figs 172 173) From the bend the latter form is termed geniculated

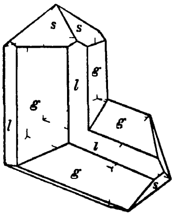


Fig 173

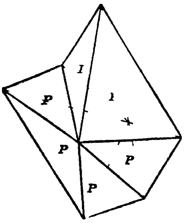


Fig 174

Hausmannite occurs in hemitropes of the primary P and on the polar edges of this other twins are symmetrically repeated a central individual appearing like a support to the others (figs 174, 175)

In the *hexagonal system* twins are very common among the rhombohedral (the hemihedral) and the tetartohedral forms, while hemitropes prevail among the hexagonal or holohedral forms The twins are generally formed by the interpenetration of two rhombohedrons, a + and a − the vertical axis being the axis of composition as in chabasite (fig 176) cinnabar levyne calcite, &c Sometimes six or more crystals, united parallel to the prismatic planes, form rosettes as in chabasite from Giant s Causeway The almost endless stellate forms of crystals of snow are built up in this manner Many of the most beautiful combinations to be seen among crystals result from this mode of arrangement

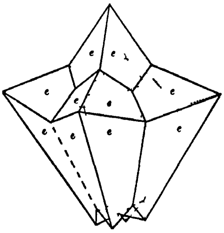


Fig 175

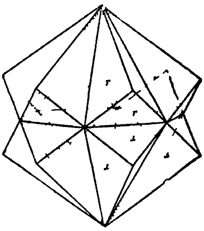


Fig 176

Parallel groupings of hexagonal prisms also occur as in apatite (fig 177)

Rock crystal in consequence of the tetartohedral character of its crystallization exhibits twins in which the double hexagonal pyramid P may be said to be separated into two rhombohedrons *P* and *r* these, though geometrically similar, are physically distinct In fig 178 the two individuals have not entirely interpenetrated and might be regarded as simply grown together with parallel axes but in fig 147 there is so complete an interpenetration that the composite character of the crystal is only evidenced through a difference in the character of the surfaces of the two halves which are most irregularly disposed

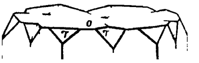


Fig 177

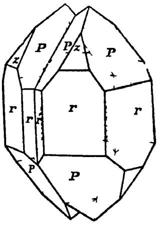


Fig 178

The hemitropes of this system often form regular crystals when the two halves have been united by a plane parallel to the base, so as to appear like a simple crystal as in fig 179 Here each end shows the forms ∞R $-\frac{1}{2}R$ but the terminal faces appear in parallel instead of alternate position Something of the same is seen in fig 180 a hemitrope scalenohedron from Derbyshire Hemitropes with the face of the primitive rhombohedron as the face of composition are also common and they are sometimes joined by a face of $-\frac{1}{2}R$ the two axes forming an angle of 127° 34 Occasionally a third individual is interposed in a lamellar form as in fig 181, where the faces of the two outer portions become parallel This is found in some pieces of Iceland spar When the crystals unite in a face of the primary rhombohedron they form an angle of 89° 8 hemitropes on this law are easily recognized by their differing so little from a right angle in the re entering bend (figs 182 183) The faces which in this species act as faces of composition are exceedingly numerous , other examples are figs 142 146, 148, and 149

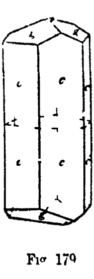


Fig 179

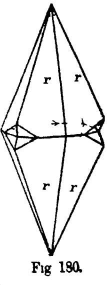


Fig 180

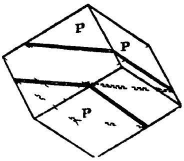


Fig 181

In the *right prismatic system* twin crystals with parallel axes are rare but with oblique axes common the faces of union being one of the faces of the prism ∞P Twins of this kind occur frequently in aragonite, cerussite mispickel, and marcasite In aragonite the crystals are partly interpenetrating, and partly merely in juxtaposition, as in fig 184, where the individuals are formed by the

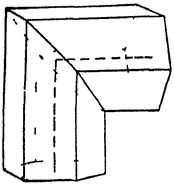


Fig 182

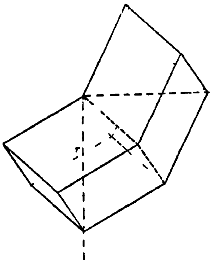


Fig 183

combination $\infty P(M)$ $\infty\breve{P}\infty(h)$, $\bar{P}\infty(k)$ In fig 185 several crystals of the same combination form a series with parallel planes of union, the inner members of which are often so shortened that they form mere films, which appear as striæ on the faces $\breve{P}\infty$ and $\infty\breve{P}\infty$ of the twin

In fig 186 four crystals, each of the combination $\infty P, 2\breve{P}\infty$, having united in inclined planes, form a circular group, which returns into itself Cerussite occurs in similar groups, building up a composite hexagonal crystal It also occurs in stellate twins of two or three individuals, as in figs 158, 159 Similar stellate combinations are also common in chrysoberyl In staurolite individuals of the prismatic combination ∞P $\infty\breve{P}\infty$, 0P combine, either as in fig 144 by a face of the brachydome having their chief axes almost at right angles, or as in fig 140 by a face of the brachypyramid $\frac{3}{2}\breve{P}\frac{3}{2}$ the chief axes and the brachypinacoids (*o*) of each of the crystals meeting at an angle of about 60° This mineral which is very frequently twinned, also forms combinations with the axes parallel (fig 187)

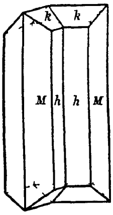


Fig 184

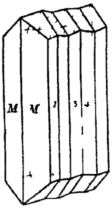


Fig 185

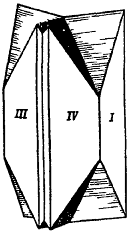


Fig 186

Fig 187

Oblique prismatic twins

In the *oblique prismatic system*, twins are by no means so frequent as hemitropes Twins of interpenetration with parallel axes, but the one turned as regards the other round a vertical axis are common in orthoclase (figs 188, 189) Such crystals are termed right handed (fig 188) and left handed (fig 189), according to the side of the crystal which has been turned In this mineral hemitropes occur around an axis normal to *M*, to *P* and to *n* (fig 529) double twins of the last two are common (fig 530)

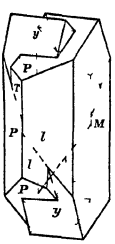


Fig 188

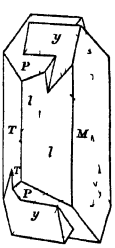


Fig 189

Twins of hemitropes.

Harmotome and phillipsite form first hemitropes and *then* twins of these, which are arranged sometimes as crosses and sometimes as double crosses (fig 190) In hemitropes of gypsum the two halves are united by a face parallel to the orthodiagonal section, as in fig 161, where the two halves have united so regularly that the faces P′, P form only one plane. In a similar manner the two halves of the augite crystal represented in fig 130 are in fig 191 united so perfectly and symmetrically that the line of junction cannot be observed on the clinopinacoid The two hemipyramids ′ (*s*) (like $-P$ (*l*) in the gypsum crystal) form at one end of the crystal a re entering, at the other a salient angle

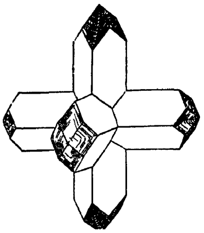


Fig 190

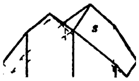


Fig 191

Hornblende (fig 192) and wolfram exhibit a similar appearance This results in the imparting a pseudo hemimorphism to certain oblique prismatic twins, which is well seen in the twins of sphene (figs 193 and 589), and in exalting the characteristic appearance of true hemimorphs, as seen in the twin of acmite (fig 194) In other cases the individuals partially penetrate each other in the direction of the orthodiagonal This mode of union is not uncommon in gypsum, and is very frequent in orthoclase Two crystals of the latter of the combination $(\infty P\infty)$, ∞P, 0P, $2P\infty$, as in fig 131, are often pushed into each other, as shown in fig 195

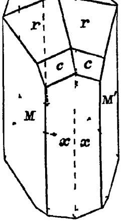


Fig 192

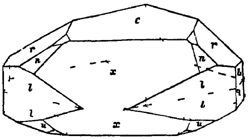


Fig 193

In the *anorthic system* some twin formations are of great importance, *e g*, as a means of distinguishing the triclinic from the monoclinic species of felspar In one variety the twin axis is the normal to the brachydiagonal chief section But in the anorthic felspars this section is not perpendicular to the base and consequently the two bases form on one side a re entering, on the other a salient angle, whereas in the oblique prismatic felspars (where the brachydiagonal chief section corresponds to the clinodiagonal) no twin crystals can be produced in conformity to this law, and the two bases fall in one plane

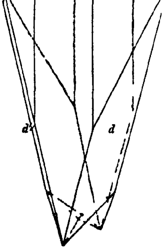


Fig 194

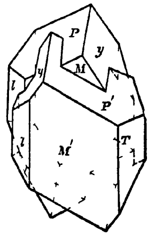


Fig 195

Albite and oligoclase very often exhibit such twins as in figs 196, 197, where the very obtuse angles formed by the faces of 0P, or *P* and *P′* (as well as those of $'\bar{P}\infty$, or *x* and *r*), are a very characteristic appearance, marking out this mineral at once as a triclinic species Usually the twin formation is repeated, three or more crystals being combined, when those in the centre are reduced to mere plates When very numerous, the surfaces *P* and *x* are covered with fine striæ, often only perceptible with a microscope A second law observed in triclinic felspars, particularly in albite and labradorite, as that the twin axis corresponds with that normal of the brachy-diagonal which is situated in the plane of the base In pericline, a variety of albite, these twins appear as in fig 198, where the two crystals are united by a face of the basal pinacoid *P*, whilst the faces of the two brachypinacoids (*M* and *M'*) form edges with very obtuse angles (173° 22') re entering on the one side and salient on the other These edges or the line of junction between *M* and *M'*, are also parallel to the edges formed by these faces and the base, or those between *M* and *P* In this case also the twins are occasionally several times repeated, when the faces appear covered by fine striæ

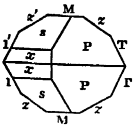


Fig 196

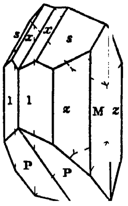


Fig 197

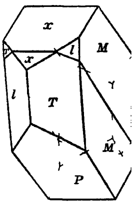


Fig 198

Cause of the Formation of Twins and Hemitropes —It has been shown above that the relative position of the molecules of crystals is determined by a polarity in the molecules themselves This polarity must exist along three lines which intersect in the centre of the molecules, and unlike poles must attract each other It has been supposed that compound crystals result from a reversion of the original polarity of the molecules of a crystal after it has attained a certain size Heat and electricity, resulting from movements in strata, might occasion such reversion during the formation of a crystal and this would suffice for the explanation of hemitropes, though not directly of geniculated crystals, and still less of intersecting twins Twins have accordingly been divided into "paragenetic and 'metagenetic The first term is applied to the ordinarily occurring twins in which the compound structure is supposed to have had its beginning in a nucleal compound molecule or to have been compound in its very origin In metagenetic twins the crystal was at first simple, but afterwards through some change in the material furnished for its increase or possibly induced in itself it received new layers, or an extension *in a reversed position*

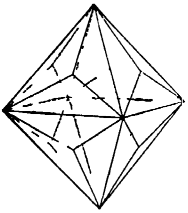


Fig 199

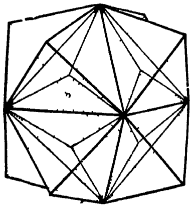


Fig 200

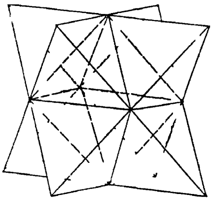


Fig 202

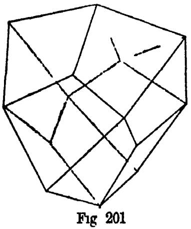


Fig 201

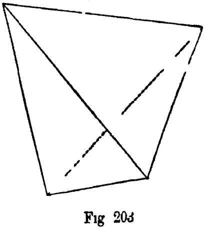


Fig 203

Rutile occurs in crystals like fig 178, but with a bend at both extremities, instead of one only Here the middle portion of the crystal is supposed to have attained a length of half an inch and then it became geniculated simultaneously at both extremities, indeed, in this mineral such geniculations are frequently repeated until the ends are bent into one another, and produce short hexagonal prisms with central depressions or even vacuities The repeated twinning which produces striation, as in calcite and the felspars and the peculiar rippled structure of amethyst, are ascribed to a similar operation, acting in an oscillatory manner

Certain intersecting twins in the cubic system may be explained simply through excessive or undue accretion of molecules along certain lines At page 351 it was shown how the three faced octahedron (fig 39) was formed through an accretion of molecules upon the faces of the octahedron along axes joining the centres of its faces (those which connect the solid angles of the cube) It was also shown that when through this accretion two faces of the triakis-octahedron (fig 199), adjacent along the edge of the octahedron, rose into one plane the rhombic dodecahedron resulted If now accretion still goes on along the same axes so that the trihedral pyramid rises above the level of the dodecahedral planes, fig 200 results This is the twin of the three faced tetrahedron (fig 201)

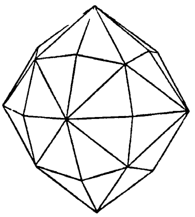


Fig 204

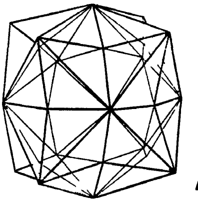


Fig 205

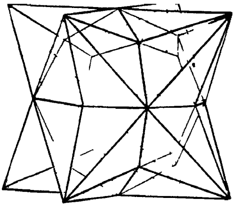


Fig 207

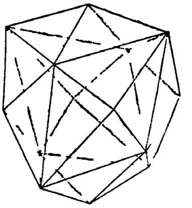


Fig 206

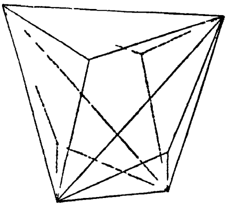


Fig 208

If the accretion is still along the same axes until the lateral edges of the adjacent pyramids fall into the same line fig 202 results and this is the twin of the simple tetrahedron (fig 203) Here accretion upon the faces of a complex holohedral form has produced a twin of a simple hemihedral form

Again, starting from the six faced octahedron (fig 204), there is produced by the same process first fig 205 the twin of the six faced tetrahedron (fig 206), and ultimately fig 207, the twin of the three faced tetrahedron (fig 208)

2 *Departure from Regularity on Account of Undue Accretion in certain Directions —Distortion of Crystals* —The laws of crystallization should produce crystal forms of perfect symmetry, these laws, however, are subject, not only to the influence of other laws, but also frequently to disturbing influences which are subject to no law Absolute symmetry, therefore, is very uncommon, crystals being generally so distorted and disguised through interference during their formation that either familiarity on the one hand or skill on the other is necessary for their recognition As the magnitude of the angles may vary somewhat, even this guide may sometimes perplex Hence it is necessary to be familiar with such departures from symmetry, and some of the more common are here noticed.

In the cubic system a cube (fig 20), lengthened or shortened along one axis, becomes a right square prism (fig 209) and if elongated in the direction of two axes is changed to a rectangular prism (fig 7) Cubes of pyrites, galena, fluor spar &c., are generally thus distorted It is very unusual to find a cubic crystal that is a true symmetrical cube In some species the cube or octahedron (or other monometric form) is lengthened into a capillary crystal or needle as happens in red copper and pyrites Crystals of acicular pyrites occur at the Newton Stewart lead mine

An octahedron flattened parallel to two of its faces is reduced to a tabular crystal (fig 210) If lengthened in the same direction, it takes the form in fig 211 or if it is still further lengthened to the obliteration of two opposite octahedral faces it becomes an acute rhombohedron (same figure)

When an octahedron is extended in the direction of a line between two opposite edges it has the general form of a rectangular octahedron and still further extended as in fig 212 it is changed to a rhombic prism with dihedral summits The figure represents this prism lying on its acute edge (spinel, fluor, magnetite)

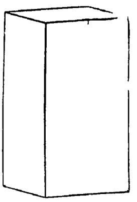


Fig 209

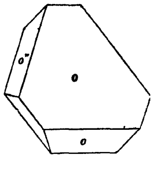


Fig 210

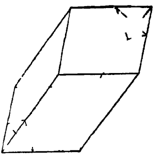


Fig 21.

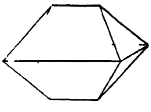


Fig 212

The dodecahedron when lengthened in the direction of the upright axis becomes a square prism with pyramidal summits (fig 213) and when shortened along the same axis it is reduced to a square octahedron with truncated basal angles (fig 214) Both these forms are modifications of the square prism the first mode of distortion is common in garnet, rendering it liable to be considered zircon, the second is seen in aplome, when it might be taken for stannite When the first of these forms is flattened as in fig 215 it resembles a form of stilbite

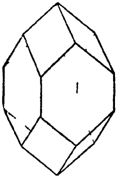


Fig 213

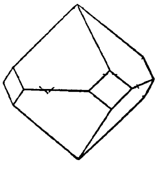


Fig 214

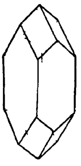


Fig 215

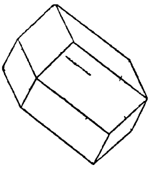


Fig 216

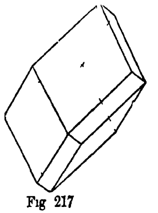


Fig 217

When a dodecahedron again is lengthened along a diagonal between the obtuse solid angles, it becomes a six sided prism with trihedral summits, as in fig 216 and when shortened in the same direction it becomes a rhombohedron which has its six acute angles truncated (fig 217) In the first case a crystal of green garnet or uwarowit would resemble dioptase in the latter colourless garnet would resemble calcite

The trapezohedron is exceedingly subject to distortions which frequently disguise it much When elongated in the direction of the upright axis it becomes a double eight sided pyramid with four sided mits (fig 218), a further elongation along the same axis would result in the obliteration of these summit faces, and in the production of a perfect double octagonal pyramid (fig 219) The first of these distortions is exceedingly common in analcime and not uncommon in garnet the latter rarely occurs in analcime Lengthened along an octahedral axis it becomes fig 220, shortened along the same it becomes fig 221 Both are seen in analcime

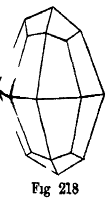


Fig 218

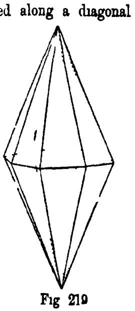


Fig 219

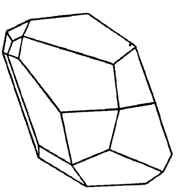


Fig 220

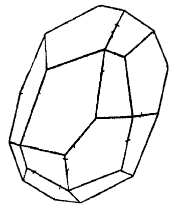


Fig 221

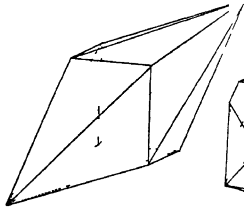


Fig 223

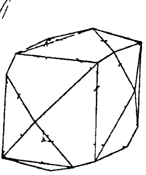


Fig 222

Of tetrakishexahedron. When the tetrakishexahedron is lengthened along a single octahedral axis it assumes the form of fig 222 still further elongated, with obliteration of one half of its planes it becomes a scalene dodecahedron resembling the "dog tooth form of calcite (fig 223) Fig 224 is a hemihedron of this form, produced by shortening along an octahedral axis, with obliteration of all the planes which do not touch the poles of that axis

In the case of modified crystals of this system the distortions are more complex Fig 225 represents a crystal of cinnamon stone from Aberdeenshire it is a combination of the dodecahedron and the trapezohedron Only four dodecahedral faces remain (*d*) and those of the trapezohedron (*n*) are of unequal size t may be best understood by regarding it as fig 218 with the four vertical faces of fig 213, so that it combines the distortions of both of these figures

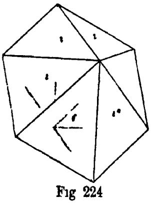


Fig 224

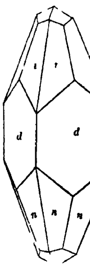


Fig 225

Crystals of diamond are very frequently distorted, though generally through curvatures of their faces

Imperfections in the Surfaces of Crystals

Of these the most important are striæ, caverns, and curvatures

Imperfection of surfaces. 1 *Striated Surfaces* —The parallel furrows on the surfaces of crystals are called striæ and such surfaces are said to be striated

Each ridge on a striated surface is enclosed by two narrow planes These planes often correspond in position to a secondary or to the primary planes of the crystal, and we may suppose these ridges to have been formed by repeated oscillation in the operation of those causes which give rise, when acting uninterruptedly, to larger planes By this means the surfaces of a crystal are marked in parallel lines with a succession of narrow planes, meeting at angles alternately re entering and salient, and constituting the ridges referred to This combination of different planes in the formation of a surface has been termed an oscillation of faces

Striation Cubes of pyrites are generally striated in such a way that the striæ on adjacent faces are at right angles to one another These lines are parallel to the intersections of the primary faces with the planes of the pentagonal dodecahedron, which is the most common form of pyrites, and they have evidently resulted from an oscillation between the primary and this secondary form

The rhombic dodecahedron is often striated parallel either with the edges, or with the longer or the shorter diagonal of its faces In the first case, seen in garnet (fig 226), there is a passage into the six faced octahedron the second results from an oscillatory combination of the dodecahedron with the regular octahedron, as in magnetite, and the last with the cube, as in aplome

Rhombohedrons of chabasite are often striated parallel to the terminal edges (fig 227) indicating an oscillatory combination between the primary faces and a secondary plane which bevels these edges

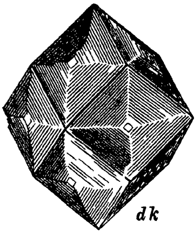


Fig 226

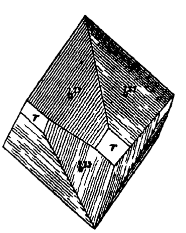


Fig 227

Striation of faces is more frequent in the rhombohedral system than in any of the others Horizontal striæ are of almost invariable occurrence in the prismatic faces of quartz, whatever be the form of the crystal The oscillation here has taken place between the pyramidal and the prismatic faces (figs 228 229 230) During its growth there seems to have been a continued effort to complete the crystal by the assumption of the terminal planes —which effort was intermittently overcome by a preponderating one to continue the deposition of matter along its main axis Quartz crystals, from these alternate efforts often taper to a point, without having any regular pyramidal face

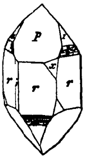


Fig 228

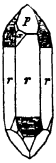


Fig 229

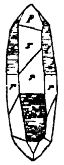


Fig 230

The lateral planes of prisms of tourmaline are very frequently convex, owing to oscillation between several lateral faces In all such cases the interfacial angles cannot be determined as they are lost in the rounding

The striations on the lateral faces of foliated minerals are merely the edges of laminæ Examples mica and gypsum

2 *Cavernous Crystals* —Crystals not unfrequently occur with a deep pyramidal depression occupying the place of each plane as is often observed in common salt galena (fig 21) and sulphur In the solution of crystals through atmospheric exposure, an approach to the same form is sometimes obtained owing to the fact that the centres of the faces yield sooner than the edges and angles Crystals of redruthite are often thus cavernous Sometimes octahedrons occur with a triangular cavity, in place of each face (fig 22) The same is met with in other forms

8 *Curved Surfaces* —Curved surfaces sometimes result from the oscillatory combination already noticed Others result from a curvature in the laminæ constituting the crystal Crystals of diamond have convex faces, and are sometimes almost spheres This mode of curvature in which all the faces are equally convex is less common than that in which a convex surface is opposite and parallel to a corresponding concave surface Rhombohedrons of spathic iron and pearl spar are usually thus curved, as is shown in fig 231 The saddle-shaped crystals of the same mineral (fig 232) are remarkable instances of several reversed curvatures in [illegible] face A singular curvature is shown in fig 233, of calcite The conical crystals of brown zinc blende, and the lenticular and conical crystals of gypsum, are other examples Crystals of quartz are sometimes curved and twisted When this takes place in the left handed and right handed crystals, the twist is to the right or left according as the crystal is right or left handed

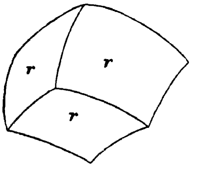


Fig 231

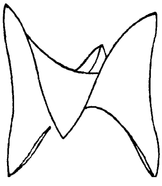


Fig 232

Dislocated crystals.

The surfaces of crystals are frequently far from flat, on account of fracture, with dislocation of the several fragments, occasioned by motion in the enclosing rock, the material of which is forced or it may be transfused, into the rents The tourmalines and beryls (fig 234) which occur in granitic dykes are very subject to this, the fragments being often bent as well as displaced A more or less simultaneous effort in the crystallization of two substances may produce a structure with the external form of one, the interior of which exhibits imbedded crystals of the other more or less perfect in their development In pegmatite or graphic granite, rude crystals of felspar contain skeleton forms of quartz of which generally only one side of the prism and two of the pyramid occur, forming a rude lettering Similar hollow quartz forms occur imbedded in garnet, radiating from its centre (fig 235) and roughening its surface from protrusion, without distorting its form Totally imbedded microscopic crystals, "microliths, are, as in the latter cases chemically non assimilable These are frequently arranged in layers in the including crystal, as in augite and leucite When there is a certain amount of chemical resemblance there may occur a definiteness in the arrangement, and if the enclosed substance crystallizes in a system differing from that of the mineral which includes it the angles of the latter are more or less distorted This is the case in ' microcline, where the intrusion of a plagioclastic felspar causes some departure from the rectangularity of orthoclase Foreign amorphous matter caught up or attaching itself to the surface of a crystal, during the process of its growth causes lines of feeble cohesion —as in the case of capped crystals of quartz Here an occasional selectiveness in the sets of faces to which the foreign matter adheres seems to indicate that it has been to some extent under the influence of a polarity in its adhesion Something of the same kind seems to have influenced the arrangement of the quartz grains caught up during the formation of the crystal of garnet shown in fig 236 The perfect modelling of rock crystals is, however, but little interfered with by the almost numberless substances which they contain

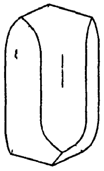


Fig 233

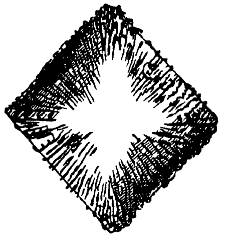


Fig 235

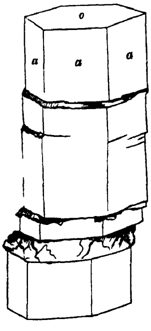


Fig 234

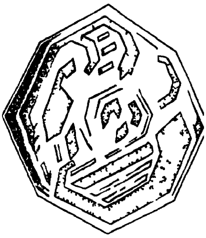


Fig 236

Aggregation of Crystals

Crystalline aggregates which pass into amorphous masses may, in their more marked or perfect form, be assigned to an imperfect twinning

Crystals are often grouped in linear series, as in native copper and silver, and thus constitute long threads or reticulations In clustered crystals those adjoining each other are generally parallel in position, and are united by a plane parallel to one of the principal sections, or to planes of common occurrence Senarmont mentions a union in galena, parallel to the octahedral faces, as common and he also describes an instance where the union was parallel to the plane $3\frac{3}{2}$.

The positions of crystals on the supporting rock seem at first to be without any regularity. But by closer inspection we detect even here the same law of harmony that governs the formation of the simple and compound crystal. The various positions assumed correspond generally with the more common kinds of composition in twin crystals. This regularity is not always manifest on account of the unevenness of the surface on which they rest. In general, however, on glancing over a surface covered with crystals, a reflexion from one face will be accompanied with reflexions from the corresponding face in each of the other crystals, showing that the crystals are similarly positioned throughout.

This tendency to parallelism in the positions of associated crystals is apparent even in crystalline aggregates. In granite, for example, which is composed of felspar, quartz, and mica, the felspar crystallizations have usually a common position, that is, the corresponding extremities lie in the same direction, or nearly so. On this account granite is cleavable in one direction more easily than in others and this direction is that of the perfect cleavage plane of the felspar the second less perfect cleavage of the felspar permits of fracture of the rock nearly at right angles to the first but as there is no such third cleavage in the felspar, the workman in fashioning the blocks of granite for paving stones, is compelled to chip or dress them off in the third direction.

The dominant action of polarity may, moreover, give a parallel position to the main axes of different minerals belonging to the same system when crystallizing in association, and even to those which belong to different systems. Fig 237 is an illustration of the first of such cases where a crystal of zircon is implanted into a crystal of xenotime, and has its main axis identically in the same line. As illustrations of the latter—a parallel position of the axes of crystals of different systems—there are records of such association in crystals of cyanite and staurolite, of muscovite and haughtonite, of albite and orthoclase. The same has been observed between crystals of rutile and specular iron—the crystals of rutile in this case having the vertical axis in the direction of a lateral axis of the specular iron. Haidinger has observed pyroxene and hornblende crystals associated in parallel positions.

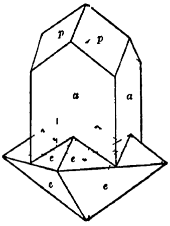


Fig 237

A prism of calcite terminating in the planes *g* (fig 106) has been observed in which each plane was covered with small crystals of quartz all lying symmetrically with their pyramids pointing towards the summit of the calcite crystal. When one mineral is changed into another, a polarity of accretion is still often seen to have dominated in the arrangement. In a crystal of calcite which had been changed into a number of minute crystals of aragonite the main axes of the latter all lay in the direction of the main axis of the original crystal of calcite.

Irregular Aggregation of Crystals.—Besides the regular unions now described, crystals are often aggregated in peculiar ways, to which no fixed laws can be assigned.

Thus some crystals apparently simple, are composed of concentric crusts or shells which may be removed one after the other always leaving a smaller crystal like a kernel with smooth distinct faces. Some specimens of quartz from Beeralston in Devonshire consist apparently of hollow hexagonal pyramids placed one within another. Other minerals, as fluor spar apatite, idocrase heavy spar and calc spar disclose a similar structure by bands of different colours. A growth rendered intermittent through the deposition of a thin layer of foreign matter is thus developed.

Many large crystals again appear like an aggregate of numerous small crystals partly of the same partly of different forms. Thus some octahedrons of fluor spar from Schlaggenwald are made up of small dark violet blue cubes whose projecting angles give a drusy character to the faces of the larger form. Such polysynthetic crystals, as they may be called are very common in calc spar.

Varieties of structure in aggregates

Forms of Crystalline Aggregates.—Crystals have often been produced under conditions preventing the free development of their forms, and, according to the direction of the axis in which the development has been checked, they may be divided into "columnar and "lamellar" arrangements.

The *columnar* structure is made up of a more or less fibrous arrangement, and this may be supposed to have accrued from the simultaneous growth of a multitude of crystals from a single or from closely adjacent centres of support, so that, while the crystals were free to elongate themselves in the direction of their main axis, their increase was restrained laterally, by their impact upon one another. When the surfaces of support are level, or consist of the opposing sides of a vein, the columns or fibres, frequently exceedingly delicate, are parallel, and not unfrequently they then have a silky lustre. In the latter of the above circumstances the fibres are disposed transversely to the vein. Examples gypsum, chrysotile, satin spar. When the surface of support is rough, or has angular projections, the fibres radiate from certain of these in all directions, producing, in a thin vein, a starlike form, whence the arrangement is called "stellular" Example wavellite. When this takes place in an open cavity, producing brush like forms, they are termed "radiant. Examples antimonite, needlestone. When the points of divergent growth are so positioned that the radiating groups interlace with one another, the structure is said to be "reticulated, from its resemblance to a net. Example tremolite. When individual members of such fibrous structure project above the general surface with acuminated extremities, they are said to be "acicular, when the protruding columns are of uniform thickness they are termed "bacillary, or rod like. Such terms as straight, curved, twisted columnar, diverging, or confused fibrous explain themselves. Such fibrous arrangements as the above may occur imbedded centrally in a rock mass, which had been the magma out of which they were formed, or they may line the inner surface of cavities, filled originally either with water or aqueous vapour. These modes of occurrence have been distinguished by Mohs as crystal groups and druses. The former includes all unions of imbedded crystals round a central nucleus, the latter those of crystals of simultaneous or regularly successive growth on a common support. In the first case, there may be spheroidal, ellipsoidal, cocks-comb, or other forms, frequently seen in marcasite, pyrite, and gypsum. In the second, spheroidal forms are less rare, but are seen in the case of several of the fibrous zeolites. In such cases surfaces more or less rough are coated, and diminished in angularity, through the hemispherical forms produced by the radiation of a multitude of fibres. Certain imitative outlines thus result from the successive deposition of layers of these crystals. These forms or uniting masses are termed 'globular when nearly spherical, "botryoidal when like bunches of grapes, "reniform or kidney shaped when the spheres are larger, more confluent, and less distinct, and "mammillated when the masses are nearer to hemispheres. Mesolite occurs in globular forms, prehnite in botryoidal, hæmatite and chalcedony in reniform, and siderite and calamine in mammillated. In all the above cases the transverse fracture of such structures discloses the fibrous arrangement of the parts, but, if the growth has been intermittent, lines of deposit, concentric with the central nucleus of each sphere, are evidenced by layers of distinct colours. Fracture or separation frequently takes place, also, along such lines. In such drusy cavities—termed 'geodes when they are circular—after a certain number of such lines of deposit, grouped arrangements which have somewhat more of free crystalline development may assume other imitative forms in which there is a certain dependence on the crystallographic character of the mineral concerned. There are thus produced coralloidal or coral like groups, fruticose or cauliflower like groups, capillary or hair like, and filiform or thread like or wire like forms. Often these groups expand in several directions, and produce arborescent, dendritic, plumose, mossy, dentiform, or other forms. Such are common among the native metals, as gold, silver, and copper. Mesolite is very frequently plumose. A 'drusy crust is the term applied to a thin rough layer of crystals, which invests either a large crystal or the surface of some other body lodged in the interior of cavities.

In the *lamellar* structure a development along the main axis would appear to have been checked, and the crystallographic force to have expended itself laterally, though this is not the invariable habit of a species under all circumstances as exemplified by baryte. This structure consists of flat crystals, plates, or leaves. It is termed "tabular when the plates are of uniform thickness, "lenticular' when they are thinner on the edges, "wedge shaped' when sharp on one edge, "scaly when the plates are thin and small, 'foliaceous when larger and easily separable, "micaceous' is also used to describe this kind of structure. It may also be curved lamellar and straight lamellar. Wollastonite, when flat lamellar, is called tabular spar, gypsum is frequently lenticular, talc scaly. Lamellar minerals when radiating from a centre often form fan shaped, wheel like, almond shaped, comb like, and other groups.

In the *granular* structure, the force of crystallization has been exerting itself along all the axes, but, from the multiplicity of crystallizing centres, there has been such mutual interference that no single individuals have been able to assume perfect or even characteristic forms. The particles in a granular structure differ much in size. When coarse, the mineral is described as coarsely granular, when fine, finely granular, if not distinguishable by the naked eye, the structure is termed impalpable. Examples of the first may be observed in granular carbonate of lime, of the

second in some varieties of specular iron, of the last in chalcedony, opal, and other species

The above terms are indefinite, but of necessity, as there is every degree of fineness of structure in the mineral species, from perfectly impalpable, through all possible shades, to the coarsest granular The term phanero crystalline has been used for varieties in which the grains are distinct, and crypto crystalline for those in which they are not discernible without the aid of a lens Granular minerals, when easily crumbled in the fingers, are said to be friable

The minute or crypto crystalline minerals form aggregates somewhat similar to the above When globular or oolitic, the minute crystals often appear to radiate from a centre or form concentric crusts These are often globular or nodular as in dolomite Somewhat similar are the stalactites and stalagmites in which the mineral (especially rock salt, calc spar, malachite, hæmatite limonite) has been deposited from a fluid dropping slowly from some overhanging body or some rent in the roof of a cave In this case there is generally found a long pendent cylinder or cone, the principal axis of which generally hollow, is vertical, whilst the marginal parts are arranged at right angles to it, except where they curve round the termination of the tube, when they become hemispherical

By far the largest masses of the mineral kingdom have however, been produced under conditions in which a free development of their forms was excluded, and are termed amorphous This has been the case with the greater portion of the minerals composing rocks or filling veins and dykes The structure of these masses on the large scale belongs to geology, but some varieties of the textures visible in hand specimens, may be noticed The individual grains or masses have seldom any regular form, but appear round, long or flat, according to circumstances and as each has been more or less checked in the process of formation Even then however, a certain regularity in the position of the parts is often observable, as in graphic granite where the axes of the skeleton crystals of quartz are parallel The rock is termed massive when the grains which form it are small, or granular when they are longer and more distinct Sometimes the rock becomes slaty, dividing into thin plates , or concretionary, forming roundish masses , at other times the interposition of some foreign substance (gas or vapour) has rendered it porous, cellular, or vesicular giving rise to drusy cavities These cavities are often empty but have occasionally been more or less filled by products of change in the rock It is named amygdaloidal when the cavities so filled have the form of an almond

Changes of Crystalline Structure

"Pseudomorphs" are minerals which appear under a form of crystallization which does not belong to the species They may be recognized either by their having no cleavage, which is most usual, or by their cleavage being altogether different in direction from that of the mineral imitated Generally they have rounded angles, rough and dull surfaces, and when broken show a granular structure The faces of the crystal, moreover, are often covered with minute crystals of a form different from that of the mineral imitated, but which is that belonging to the substance now present Occasionally the resemblance to real crystals is so perfect, from the perfect polish of the faces, that they are distinguished with difficulty They may be frequently found still undergoing change

Pseudomorphs classified.

Pseudomorphs have been classed under four heads —

1 *Pseudomorphs by Alteration* —Formed by a gradual change of composition in a species Of these there are two varieties they may be pseudomorphous by loss of an ingredient, or by addition of an ingredient , change of augite to steatite is an example of the first, and of galena into anglesite is one of the second

2 *Pseudomorphs by Substitution* —Those formed by the replacement of a mineral which has been removed or is gradually undergoing removal , *e g* , galena takes the form of pyromorphite

3 *Pseudomorphs by Incrustation* —Those formed through the incrustation of a crystal, which may be subsequently dissolved away Often the cavity is afterwards filled by infiltration , *e g* change of fluor to quartz

4 *Pseudomorphs by Paramorphism* —Those formed when a mineral passes from one dimorphous state to another , *e g* , change of aragonite to calcite

These different kinds of change are not always distinguishable In some cases a change may take place through alteration of the surface, and then, this process ceasing, the interior may be dissolved out, leaving a pseudomorph like one of incrustation , or a pseudomorph that appears to be a result of mere chemical alteration may be wholly due to substitution simply.

Again, changes of scapolite to a felspar and of augite to uralite (hornblende), have been considered by Scheerer examples of paramorphism,—scapolite being considered dimorphous with some felspars, and augite with hornblende But, while such paramorphic changes undoubtedly take place with aragonite, their occurrence in these silicates—which are common associates in the same rock, and must have been formed under like circumstances—is hardly probable

Where mineral bodies have taken the form of organisms, it is more a case of molecular replacement than of true pseudomorphism

Pseudomorphism should be understood, however, to consist, not simply in alteration of crystals but in many instances of changes in beds of rock Thus all serpentine, whether in mountain masses or in simple crystals, has been formed through a process of pseudomorphism—or, in more general language, of metamorphism—of olivine and augite The same is true of other magnesian rocks, as steatitic, talcose, and chlorite slates The crystalline rocks often offer examples of a change similar in nature The graphite of these rocks is probably but a metamorph of some vegetable organism Thus the subject of metamorphism as it bears on all crystalline rocks and that of pseudomorphism, are but branches of one system of phenomena , the chemistry of both is the same, and a knowledge of such changes is indispensable to a study of the older rock strata of the earth

The common change of pyrites forming the main ingredient of the upper part of metallic lodes, to earthy red or brown iron ore, thus producing the "gossan of miners is one of many examples of these processes now in progress Often the gossan contains disseminated silver or gold derived from the decomposed ores This is a case of pseudomorphism, as truly as when a simple crystal of pyrites becomes limonite the mode of change and its laws are the same Again, phosphates vanadiates and arseniates of lead, &c , as well as carbonates and sulphates are among the surface species or those that occupy the upper part of metallic lodes they are the results of alteration within those depths to which atmospheric agencies penetrate

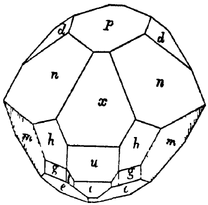


Fig 238

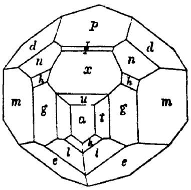


Fig 239

Pseudomorphs are always records of past existences in some cases they may be the only evidence we possess of such prior existence Figs 238, 239 are pseudomorphs of quartz or hornstone after datholite the measured angles of these crystals show that the imitated crystal was datholite, but that mineral does not now occur in crystals of either of these forms

The process of petrification of organic bodies is in reality a species of pseudomorphic formation, and has been produced in all the above modes External and internal casts of organic bodies are not uncommon In other cases the original substance has been replaced by some mineral which has preserved not merely the external form but even the minutest detail of internal structure,—so that the different kinds of wood have been distinguished in their silicified trunks The most common petrifying substances are silica and carbonate of lime In encrinites, echinites belemnites, and other fossils, the crystals of calc spar often occur in very regular positions In some varieties of petrified wood both the ligneous structure and the cleavage of the calc spar are observable

Different from the above are mineralized bodies in which the original structure is still retained, but their chemical nature partially changed In these a complete series may be often traced, as from wood or peat, through the varieties of brown coal, common coal, anthracite, and graphite

Origin pseudo morph

Causes of Change —The causes of change are the simplest and most universal operations about us —(1) the process of gradual alteration to which some substances are liable on account of the presence of oxygen and carbonic acid in the atmosphere, and the reaction of substances thus formed on adjacent ingredients, aided or promoted by electrical currents or by heat , (2) the solvent power of ordinary waters, cold or hot, or of steam (3) reactions, in accordance with chemical principles, of the ingredients dissolved in these waters, or in mineral or sea waters, heated or at the ordinary temperature; (4) the action of gases exhaling from the earth; (5) changes referable to volcanic action.

Ordinary waters hold in solution, as is well known, more or less of mineral matter. When water containing carbonic acid is passed through a large number of ordinarily occurring minerals, it gives evidence of the presence of an alkali, or lime, or magnesia, and some of these minerals give the tests even with the first drops. Pure water gives with many of them a similar result, but more slowly. Limestone in forty-eight hours yields soluble ingredients to the extent of 0·4 to 1 per cent. of the whole mass. The lime, magnesia, and alkalies appear in the condition of carbonates; and the iron passes from the state of carbonate to that of peroxide during evaporation. The silicates of magnesia, lime, and manganese are especially ready in yielding to this action. Silica, however, is more soluble in ordinary than in carbonated water.

These facts illustrate two important points:—(1) that ordinary waters lying upon and filtering through the earth's crust are constantly active in dissolving and decomposing minerals and rocks, and that even species reputed indestructible are thus acted upon; and (2) that the waters are thus furnishing themselves with agents capable of effecting other chemical changes. These waters penetrate all rocks, as well as percolate through soils. Hence the action is a universal one, everywhere going on; and the results are universal. Bones, shells, corals, and animal remains generally are also sources of carbonate of lime, phosphates, and fluorides; and plants may contribute also potash and soda, and sometimes silica.

Carbonic acid is a constant ingredient of the atmosphere, and is dissolved by the rains as they descend; hence this active decomposing agent is present in all ordinary waters; but it is also a result of different mineral changes. Sulphate of iron along with vegetable matters gives oxygen to the carbon of the vegetable matter, and thus produces carbonic acid and pyrites or sulphuret of iron; and the large quantities of pyrites in coal beds show on how grand a scale this process has taken place. Sulphate of zinc in a similar manner produces carbonic acid and blende or sulphuret of zinc. Bischof observes that the carbonic acid which has thus been eliminated must have been sufficient in quantity to make an atmosphere of carbonic acid equal in height to our present atmosphere. Again, decomposition of sulphurets produces sulphuretted hydrogen; this by the oxidating action of the atmosphere forms sulphuric acid; and the sulphuric acid acting on limestone produces gypsum, and liberates carbonic acid. Sulphurous acid is also generated in the neighbourhood of volcanoes, and rapidly becomes sulphuric acid, with the same result. Moreover, silica in waters, if aided by heat, will decompose limestone and liberate carbonic acid. Hence it is that this gas is exceedingly common in exhalations from mineral springs; indeed it occurs more or less in all waters.

The dissolving and decomposing action of carbonated waters is therefore general. The sea also partakes of this character, and in virtue of the numerous salts which it holds dissolved is a powerful agent in carrying on the changes to which the process leads. Such changes and the various pseudomorphs to which they give rise have to be regarded as types and evidences of vast metamorphic transformations,—processes either of decay or of reformation, which have modified widespread rock masses, and which are at the present time altering the structure of the crust of the earth. It is through a study of pseudomorphs, and of the processes which have gone to form them, that mineralogy is to become the germ from which alone the petrological department of geology can have its true development, and become a living instead of a merely speculative science.

PHYSICAL PROPERTIES OF MINERALS

Characters Depending on Light

There are few more interesting departments of science than the relations of mineral bodies to light, and the modifications which it undergoes either when passing through them or when reflected from their surface. In this place, however, we only notice these phenomena so far as they point out distinctions in the internal constitution of minerals, or furnish characters for distinguishing one species from another.

Lustre.—Though the varieties of lustre admit of no precise or mathematical determination, they are of considerable value in mineralogy. One highly important distinction founded on them is that between minerals of metallic and non-metallic aspect or character. Transparency and opacity nearly coincide with this division,—the metallic minerals being almost constantly opaque, the non-metallic more or less transparent. Minerals which are perfectly opaque, and show the peculiar brilliancy and opacity of surface of polished metals, are named metallic; those which possess these properties in an inferior degree are semi-metallic, and those without these properties are non-metallic.

Lustre has reference to either the intensity or the quality of the reflected light, considered as distinct from colour. Several degrees in intensity have been named:—(1) splendent, when a mineral reflects light so perfectly as to be visible at a great distance, and lively and well defined images are formed in its faces, as galena, specular iron, or cassiterite; (2) shining, when the reflected light is weak, and only forms indistinct and cloudy images, as heavy spar or calcite; (3) glistening, when the reflected light is so feeble as not to be observable at a greater distance than arm's length, and no longer forms an image, as talc; (4) glimmering, when the mineral held near the eye in full clear daylight presents only a number of small shining points, as red hæmatite and granular limestone. When, as in chalk or kaolin, the lustre is so feeble as to be indiscernible, the mineral is said to be dull.

In regard to the kind or quality of the lustre, the following varieties are distinguished:—(1) the metallic, seen in much perfection in native metals and their compounds with sulphur, and imperfectly in glance coal; (2) adamantine, found in beautiful perfection in the diamond, and in some varieties of blende and cerussite; a modification is metallic adamantine, as seen in wolfram and black cerussite; (3) vitreous or glassy, seen in rock crystal, or common glass, or, inclining to adamantine, in flint glass; sub-vitreous is seen in broken calcite; (4) resinous, when the body appears as if smeared with oil, as in pitchstone, blende, and garnet; (5) waxy, like beeswax, as seen in wax opal and ozocerite; (6) pearly, like mother of pearl, seen in gyrolite, talc, heulandite; (7) silky, the glimmering lustre seen on fine fibrous aggregates like amianthus, tremolite, chrysotile, krokidolite.

These degrees and kinds of lustre are generally exhibited differently by unlike faces of the same crystal, but always similarly by like faces. The lateral faces of a right square prism may thus differ in lustre from that of a terminal face. Thus the lustre of the lateral faces of apophyllite is vitreous, while that of the terminal, at right angles thereto, is pearly; chrysotile is silky when split along the fibres, dull when at right angles to them.

The surface of a cleavage plane, in foliated minerals, generally differs in lustre from the sides; and here again in some cases the latter are vitreous, while the former is pearly, as in heulandite.

As shown by Haidinger, only the vitreous, adamantine, and metallic lustres belong to faces perfectly smooth and pure. In the first the index of refraction of the mineral is 1·3 to 1·8; in the second, 1·9 to 2·5; in the third, above 2·5. The pearly lustre is a result of reflexion from numberless lamellæ, or cleavage planes, within a translucent mineral; and in hydrated minerals, as in the zeolites, it is the result of incipient change,—namely, a loss of water which ensues upon exposure to the atmosphere.

Colour.—This is a property which is of very inferior value. Minerals are so seldom, if ever, absolutely pure that very minute quantities of an intensely coloured impurity may impart colour to a substance inherently colourless, or overpower a feebler colour which may be its own.

Some few minerals have colour so strong, or have a constitution so little susceptible of intermixture, that they retain almost unimpaired the colour special to them. Such a substance is pyrite; its brass yellow colour may be heightened to gold yellow by intermixture with copper sulphide, or it may be slightly bleached by arsenic; but the nature of its composition does not admit of the intrusion of ordinary colouring ingredients. The yellow of native gold, again, may be paled by impoverishment with the white of silver, down to the dull tint of electrum; but no foreign colouring matter can intrude itself into a metallic mass. Such substances as these,—native metals, sulphides, and oxides,—have colours essential to them, dependent on their constitution, and to a great extent characteristic of the species.

A second class of minerals are colourless of themselves, and thus very subject to the influence of minute quantities of foreign tinctorial impurity. These are absolutely transparent and devoid of colour when in crystals, but white and opaque when reduced to powder, as ice and snow, calcite and chalk, rock-crystal and sand. But such substances are generally coloured; "muddied" it would be called in the first case, though it is equally so with the others. Such false colour may be imparted in several ways. It may be (1) from their holding dissolved some colouring matter; (2) from mechanical mixture of colouring substances such as metallic *oxides, or minute crystals ("endomorphs") of another mineral, or*

(3) from chemical replacement,—the substitution of a smaller or larger quantity of a coloured isomorphous ingredient

As illustration of the first, silica, colourless in rock crystal, has been found of almost every tint, due frequently to volatile hydrocarbons which are dissipated by heat Fluorite also, found of almost every shade of every colour, may possibly be to a certain extent referred here

Quartz, felspar, and calcite are often coloured accidentally by imbedded layers of foreign "inclusions, or by ' spangling endomorphs These are mechanically mixed, so far as regards their presence in a structure of different and non assimilable chemical composition, but crystallographically arranged They either mark the lines of interrupted or intermittent growth or, in the case of endomorphs, the axial positions of the minute intruding foreign crystals lie in one plane, or in the same sets of planes

As an instance of colours introduced through definite chemical replacement, calcite may be cited Carbonate of lime is colourless if a portion of this be replaced by carbonate of magnesia there is a certain amount of pearly opacity if by carbonate of manganese of a pink tinge, if by carbonate of iron, of yellow, which may be increased through oxygen absorption and "weathering to an ochre tint, and ultimately to a dark brown

Sulphuret of zinc, chemically white and mineralogically transparent may, through metallic substitution be found of almost all tints of yellow, orange, brown, and black Again hornblende augite, and garnet —silicates which in their purest states of tremolite, malacolite and water garnet are colourless —acquire green brown, red, and black tints from the assimilation of other metallic silicates

Hence it would appear that a very advanced practical knowledge of the subject is necessary to enable us to avail ourselves of the information which is to be derived from this external feature

The accidentally coloured minerals sometimes present two or more colours or tints, even in a single crystal —very remarkable examples occurring in fluor spar apatite sapphire, amethyst tourmaline and cyanite This is still more common in compound minerals on which the colours are variously arranged in points, streaks, clouds, veins, stripes bands or in brecciated and ruin like forms Some minerals again change their colour from exposure to light the air, or damp Then either the surface alone is affected or ' tarnished, and appears covered as with a thin film producing in some minerals, as silver and arsenic only one colour, in others as chalcopyrite hæmatite bismuth stibine and anthracite, various or iridescent hues when they are said to have a pavonine lustre Or occasionally the change pervades the whole mineral, the colour either becoming paler, or disappearing, as in chrysoprase and rose quartz or becoming darker as in brown spar siderite, and rhodonite In a few minerals a complete change of colour takes place, as in heterosite, and in the chlorophæite of the Western Isles of Scotland, which, on exposure for a few hours, passes from a transparent yellow green to black These mutations are generally connected with some chemical or physical change The tarnished colours sometimes only appear on certain faces of a crystal belonging to a peculiar form Thus a crystal of copper pyrites (like fig 89) has one face P free from tarnish the faces *b* and *c*, close to P, dark blue, the remainder of *c*, first violet, and then, close to P gold yellow

Some crystalline minerals exhibit in certain directions a very lively play or change of colours from reflected light It is well seen in many various hues on the cleavage planes of labradorite and seems produced by a multitude of very thin quadrangular pores interposed in the mineral, like minute parallel laminæ On the cleavage planes of hypersthene it appears copper red, and is occasioned by similar pores or by numerous small brown or black laminæ of some foreign substance interposed in a parallel position between the planes of the hypersthene The chatoyant or changing colours of the sun stone arise from scales of hæmatite similarly interposed, and that of avanturine from scales of mica The play of colour in the noble opal seems to be produced very nearly in the same manner as that in the labradorite A similar opalescence is seen in certain minerals when cut in particular forms In the sapphire cut hemispherically over the chief axis it appears like a star with six rays in garnet it shows four rays in certain varieties of chrysoberyl and of adularia it has a bluish tint and it is also very remarkable in the cat s eye variety of quartz Iridescence often arises from very fine fissures, producing semicircular arches of prismatic tints which, like the colours of thin plates in general are referred to the interference of light

Streak —This name is applied to the appearance and the colour of the line or furrow produced in minerals by drawing the edge of a hard tempered knife or file along their surface, or to the stain obtained by rubbing a soft mineral on such a substance as paper or porcelain Taken along with the hardness, which may to a certain extent be determined by the same operation, it is one of the most valuable tests which we possess

The furrow may be lustrous or it may be dull Powder or splinters may lie along its course, or a still adherent ridge may have been merely rolled over The furrow and the powder may each be possessed of colour, though such may not be distinguishable in the mineral, or may have a colour quite different from that of the mineral Three illustrations of the usefulness of this test may suffice Argentiferous gold, chalcopyrite, and pyrite, differing immensely in value, may readily be mistaken for each other The knife, when drawn along the surface of the first, sticks in it, ruts up an adhering ridge and leaves a shining streak of the same colour as the specimen When drawn along the second it ruts up a trench covered with a dusty powder which when rubbed on paper or in the hand is greenish yellow When drawn along the third it has no effect, as pyrite is harder than the knife Psilomelane, hæmatite, and limonite all occur in black glossy, stalactitic forms, and have all been termed ' black hæmatite There is here also great difference in the value The knife makes little impression on psilomelane, but leaves a blue lustrous line it makes a blood red line in hæmatite, and a rich ochre yellow in limonite Graphite and molybdenite both crystallize in hexagonal plates both occur in the same rocks, both have a grey black colour and a brilliant metallic lustre, both stain the hands or paper, the streak of the first—best seen on paper—is black, tending to blue, that of the last is greenish Rough porcelain is the best material for determining the streak of soft minerals

Transmission of light.

Diaphaneity —Minerals, and even different specimens of the same species, vary much in this quality Some transmit so much light that small objects can be clearly seen, or letters read, when placed behind them, such are named transparent They are semitransparent when the object is seen only dimly, as through a cloud, and translucent when the light that passes through is so broken that the form of the object can be no longer discerned some minerals are only thus translucent on the thinnest edges Others transmit no light, and are named opaque

Double refraction

Refraction —It has already been mentioned that most crystals—all, in fact, except those of the cubical system—exhibit the phenomena of double refraction For a general explanation of these phenomena the reader is referred to LIGHT, vol xv p 609 *sq*

Optic axis

The direction in which there is no double refraction is named the optic axis of the crystal —sometimes less happily the axis of double refraction Now in certain minerals it is found that there is only one direction with this property while in others there are two such directions and they have in consequence been divided into uniaxal and binaxal To the former belong all crystals of the tetragonal and hexagonal systems to the latter all those of the other three systems In the former the optic axis coincides with or is parallel to the crystallographic chief axis In some uniaxal crystals the index of refraction for the extraordinary ray is greater than for the ordinary ray and in others it is smaller According as it is greater or less they are said to have positive (attractive) or negative (repulsive) double refraction

Quartz is an example of the former the index of refraction according to Malus, being for O=1 5484, for E=1 5582 calc spar of the latter, the index of O being =1 6545, that of E 1 4833 The index of E is in both cases taken at its maximum

It should be observed that the optic axes are not single lines, but directions parallel to a line, passing through every point of the crystal It is also important to remark that this property divides crystals into three precise groups —the cubic with single refraction, the tetragonal and hexagonal with double refraction, and uniaxal, those of the other three systems also double, but binaxal These properties are therefore of the greatest use in determining the system to which a mineral belongs

Polarization

Polarization —Intimately connected with this property is that of the polarization of light, which affords an easier means of determining mineralogical characteristics than the direct study of double refraction For the elements of this subject see LIGHT, vol xv p 611 *sq*

While a consideration of the optic axes enabled us merely to arrange the systems of crystallization in three groups, the phenomena of polarization not only bear out a further subdivision of the whole into the above six systems, but disclose, in many cases, phenomena markedly special to individual species The optical consideration of these phenomena enables us to fix three directions at

Axes of optical elasticity right angles to one another—called the axes of optical elasticity—such that the effect of the crystal on the luminous vibrations of the elastic ether is a maximum in one of these directions, a minimum in a second, and a maximum minimum in the third The length of these axes is chosen in terms of this action In certain cases the direction of the axes of optical elasticity is different for light of different colours

The position of these axes in relation to the crystallographic axes, and the ratios of their lengths, enable us to class all crystals as follows —

1 Crystals of the cubic system Here the three axes of elasticity are all equal The refraction is simple

2 Crystals of the tetragonal and of the rhombohedral systems Two of the axes of optical elasticity are equal in these systems, the third is greater or less according as the crystals are negative or positive The two equal axes lie in a plane perpendicular to the principal crystallographic axes, the third axis coincides with the principal axis

3 Crystals of the right prismatic system The direction of the three axes of optical elasticity coincides with the crystallographic axes, taken parallel to the diagonals of the base of the rhombohedron and to the vertical edge of the prism (the primitive parallelepiped of Levy)

4 Crystals of the oblique prismatic system Only one of the axes of optical elasticity coincides necessarily with the crystallographical horizontal axis or the diagonally horizontal axis of the rhombic base the direction of the two others not having any evident relation *a priori* with the inclined or diagonally inclined axis of the base and with the vertical axis (or vertical edge of the primitive parallelepiped)

5 Crystals of the anorthic system The three axes of optical elasticity have no relation that can be assigned *a priori* to the crystallographic axes whatever position may be assigned to these in relation to the primitive solid

In crystals belonging to the last three systems the three axes of elasticity are unequal

The axes of elasticity are in general such that a ray passing through the crystal in the direction of any one of them is divided into two, which follow that direction with different velocities depending on the lengths of the other two axes To any other direction there will in general also correspond two different velocities but their ratio will now depend in a more complex manner on all three axes In two directions (and only in two, if the axes are all unequal) the ratio becomes unity, or the ray is not divided These directions are the optic axes

The displacement of the axes of elasticity for light of different colours already mentioned takes place for two axes in crystals of the oblique prismatic system and for all three axes in the anorthic (*i e* doubly oblique) system In the other systems it does not occur

In order to follow the distinctive features of the different systems farther it is necessary to consider the colour phenomena which they display when examined in a beam of polarized light Various instruments have been devised for this purpose, as, *e g*, the polarizing apparatus of Nörrenberg fitted with a condensing lens below and above the crystal slice, or with a low power (3 in h) eye piece The polariscope of Hoffman of Paris is more efficient but the apparatus of Descloizeaux (fig 240) who has made this mode of investigation a special study has the widest scope of usefulness In this apparatus a blackened mirror is employed for polarizing the light taking the place of a tourmaline plate, a Nicol's prism or a bundle of thin glass The mirror is inferior to the other two in completeness of polarizing power and in not admitting of rotation while it shares this defect with the last It is, however, superior to all in extent of field while it does not, like the first, affect white light A Nicol's prism is used for examining or analysing the light which passes

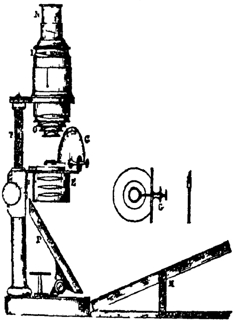


Fig 240 —Apparatus of Descloizeaux

The description of the many beautiful phenomena that may be observed with polarizing apparatus when applied to sections of crystals belongs to the subject of OPTICS (PHYSICAL), to which heading also we must refer for the phenomena of circular polarization

Optic properties of composite crystals *Double Refraction and Polarization of Composite Crystals* —In all the crystallized bodies whose action upon light we have been considering, the phenomena are identical in all parallel directions, the smallest fragment having the same property as the largest, from whatever part of the crystal it is taken In the mineral world, however (and among the products of artificial crystallization), there occur crystals which are composed of several individual crystals whose axes are not parallel These crystals sometimes occur in such regular symmetrical forms that mineralogists have long regarded them as simple forms, and it is probable that they would have still been so viewed if they had not been exposed to the scrutiny of polarized light

A composite structure has been observed in the case of Brazilian topaz sulphate of potash, and apophyllite Bipyramidal sulphate of potash, which Count Bournon supposed to be a simple crystal, was found to be a tesselated crystal, composed of three pairs of crystals of the prismatic sulphate of potash combined so that each pair had their principal axes parallel When exposed to polarized light, each pair gave the system of binaxal rings, and when held at a distance from the eye had the tesselated appearance shown in fig 241, each opposite pair of the triangles having the same tint

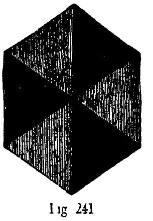


Fig 241

The most remarkable of this class of minerals is the tesselated apophyllite The examination of this body by polarized light is due to Brewster For his results the reader is referred to his paper in the *Edinburgh Transactions* vol ix p 323

Figs 242, 243 are representations of the figure produced in polarized light by an internal slice of the barrel or cylindrical apophyllite from Kudlisaet, in Disco Island The figures are from different specimens The shaded part of them has only one axis of double refraction, while the four sectors have two axes The mechanical structure of the cleavage planes resembles the optical figure even after the planes are ground

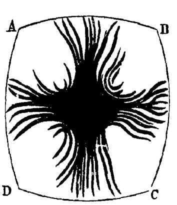


Fig 242

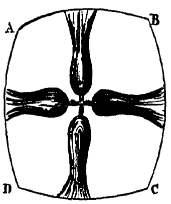


Fig 243

The minerals stilbite, heulandite chabasite, and many others, are similarly complex in structure

Crystals with Planes of Double Refraction —Analcime, a mineral ranked among the cubical crystals was found by Brewster to be singular in its action upon light, and to exhibit the extraordinary property of many planes of double refraction, or planes to which the double refracting structure was related in the same manner as it is to one or two axes in other minerals It crystallizes most commonly in the form of the icositetrahedron If we suppose a complete crystal of it to be exposed to polarized light, it will give the remarkable figure shown in fig 244, where the dark shaded lines represent planes in which there is neither double refraction nor polarization —the double refraction and the tints commencing at these planes and reaching their maximum in the centre of the space enclosed by three of the dark lines When light is transmitted through any pair of the four planes which are adjacent to any of the three axes of the solid, it is doubly refracted the least refracted image being the extraordinary one and consequently the double refraction negative in relation to the axes to which the doubly refracted ray is perpendicular If we suppose the crystal to have the form of a

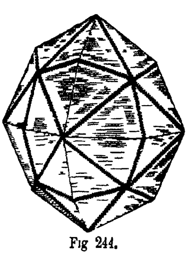


Fig 244.

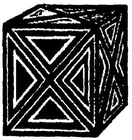


Fig 245

cube, the planes of double refraction will be, as in fig 245, a plane passing through the two diagonals of each face of the cube

The tints vary as the square of the distance from the nearest plane of double refraction

Pleochroism —Closely connected with double refraction is that property of transparent minerals named pleochroism (of many colours), in consequence of which they exhibit distinct colours when viewed by transmitted light in different directions Crystals of the cubic system do not show this property, whilst in those of the other systems it appears in more or less perfection,—in tetragonal and hexagonal minerals as dichroism (two colours), in the rhombic and clinic systems as trichroism (three colours) In most cases these changes of colour are not very decided, and appear rather as different tints or shades than as distinct colours The most remarkable of dichromatic minerals are the magnesian mica from Vesuvius, the tourmaline, and ripidolite, of trichromatic, iolite, andalusite from Brazil, diaspore from Schemnitz, and axinite

In a specimen of yellow Iceland spar the extraordinary image is of an orange yellow colour, while the ordinary image is yellowish white Along the axis of double refraction the colour of the two pencils is exactly the same, and the difference of colour increases with the inclination of the refracted ray to the axis This is the invariable law of the phenomena in uniaxal crystals Sir John Herschel found several tourmalines to have a blood red colour along the axis, and at right angles to it to be yellow green There can be little doubt that this property will be found in every crystal of sufficient refraction Even if the crystal is colourless, a slight inequality in the intensity of the two images may be observed, and when it is distinctly coloured the difference of intensity is very easily seen, even when the two colours are not of a different kind

The phenomena of dichroism are best seen in crystals with two axes of double refraction, and are well exemplified in iolite, a mineral which crystallizes in six or twelve sided prisms These prisms are of a deep blue colour when seen along the axis, and of a yellowish brown colour when viewed in a direction perpendicular to it

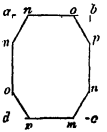


Fig 246

If *abcd* (fig 246) is a section of the prism of iolite in a plane parallel to the axis of the prism the transmitted light will be blue through the faces *ab* and *dc*, and yellowish brown through *ad*, *bc*, and in every direction perpendicular to the axis of the prism If we grind down the angles *a*, *c*, *b*, *d*, so as to replace them with faces *mn*, *m n* and *op*, *o p*, inclined 31° 41 to *ad*, or to the axis of the prism, then, if the plane *abcd* passes through the optic axes, we shall observe by transmitting polarized light through the crystal in the directions *ac* *bd* and subsequently analysing it a system of rings round each of these axes The system will exhibit the individual rings very plainly if the crystal is thin, but if it is thick, we shall observe, when the plane *abcd* is perpendicular to the plane of primitive polarization some branches of blue and white light diverging in the form of a cross from the centre of the system of rings, or the poles of no polarization, as shown at *p* and *p* (fig 247), where the shaded branches represent the blue ones The summits of the blue masses are tipped with purple, and are separated by whitish light in some specimens and yellowish light in others The white light becomes more blue from *p* and *p* to *o*, where it is quite blue, and more yellow from *p* and *p′* to *c* and *d*, where it is completely yellow When the plane *abcd* is in the plane of primitive polarization, the poles *p* *p* are marked by spots of white light, but everywhere else the light is a deep blue

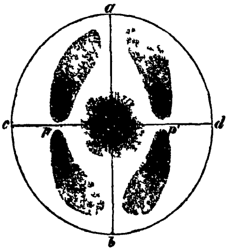


Fig 247

In the plane *cadb* (fig 247) the mineral, when we look through it by common light, exhibits no other colour but yellow, mixed with a small quantity of blue, polarized in an opposite plane The ordinary image at *c* and *d* is yellowish brown, and the extraordinary image faint blue, the former receiving some blue rays and the latter some yellow ones from *c* and *d* to *a* and *b*, where the difference of colour is still well marked The yellow image becomes fainter from *a* and *b* to *p* and *p′*, till it changes into blue, and the faint blue image is strengthened by other blue rays, till the intensity of the two blue images is nearly equal As the incident ray advances from *c* and *d* to *p* and *p*, the faint blue image becomes more intense, and the yellow one, receiving an accession of blue rays, becomes of a bluish white colour The ordinary image is whitish from *p* and *p* to *o*, and the extraordinary is deep blue, but the whiteness gradually diminishes towards *o*, when they are both almost equally blue

The principal axis of double refraction in iolite is negative. The most refracted image is purplish blue, and the least refracted one yellowish brown

Brewster found that the dichroism of several crystals is changed by heat, and that in some cases this property may be communicated to them Babinet found that all negative crystals, such as calcareous spar, corundum (including ruby and sapphire), tourmaline, and emerald absorb in a greater degree the ordinary ray, with the exception of beryl, apatite, and some apophyllites while positive crystals, such as zircon, smoky quartz, sulphate of lime, and common apophyllite, absorb in a greater degree the extraordinary ray Babinet found also that certain crystals, such as red tourmaline and ruby, transmit rays of their peculiar colour without being polarized,—in which cases the black cross of their system of rings is coloured and this unpolarized light exists both in the ordinary and extraordinary ray

Haidinger devised an instrument for showing and for testing the pleochroism of minerals In fig 248 *p* is an oblong cleavage rhombohedron of Iceland spar which has two glass prisms *w*,*w* of 18° cemented to its ends with Canada balsam This combination is placed in a metallic case which has a convex lens *l* at one end and a square hole *o* about the fifteenth of an inch in width at the other The lens is of a focal distance which shows an object held about half an inch from the square hole

FIG 248 —Section of Dichroiscope

On looking through the lens and prisms two images of the square hole are seen just touching each other The light of the one image is polarized in the plane which intersects the short diagonal of the prism that of the other is polarized in the plane of the longer diagonal When a pleochroic crystal or fragment is held at focal distance and examined by transmitted light then on the turning of the instrument bringing the polarization of its planes into coincidence with those of the crystal the two images of the square opening will show the colours of the oppositely polarized pencils of which the light transmitted by the crystal is composed, thus constitutes its pleochroism The dichroism is then seen by looking through the crystal in one direction only and the contrast of the two colours is made more obvious

Phosphorescence —This is the property possessed by particular minerals of emitting light in certain circumstances, without combustion or ignition

Thus some minerals appear luminous when taken into the dark, after being for a time exposed to the sun s rays or even to the ordinary daylight Many diamonds and also calcined barytes exhibit this property in a remarkable degree less so aragonite, calc spar, and chalk Many minerals including the greater part of those thus rendered phosphorescent by the influence of the sun also become so through heat Thus some topazes diamonds and varieties of fluor spar become luminous by the heat of the hand, other varieties of fluor spar, and phosphorite require a temperature near that of boiling water whilst calc spar and many silicates are only phosphorescent at from 400° to 700 Fahr

Electricity produces phosphorescence in some minerals as in green fluor spar and calcined barytes In others it is excited when they are struck rubbed split, or broken as in many varieties of zinc blende and dolomite when scratched with a quill pieces of quartz when rubbed on each other, and plates of mica or needles of pectolite when suddenly separated

The light emitted by phosphorescent minerals is of various tints The variety of fluor called chlorophane emits, as its name expresses, a green light The same particle may emit varying tints, as in the fluor from Aberdeenshire, which, as the heat falls, or the energy of the phosphorescence wanes, emits tints which pass from violet, through blue, green, and yellow, to dull purplish red The yellow blende from the same place is vividly phosphorescent when heated Fluor generally phosphoresces with a tint of its own colour

Too high a heat destroys the phosphorescence, which may, however, be restored by either exposure to sun s light or to electricity.

The mineral phosphoresces vividly when the discharge passes through it, it generally phosphoresces with a different colour after it has been thus recharged

Fluorescence is the property whereby rays of light of a refrangibility higher than those ordinarily seen by the human eye are rendered visible The substance when placed in the violet end of the spectrum, and carried beyond it into the invisible rays, becomes luminous, through "degrading the rays of extreme refrangibility This property is well marked in those varieties of fluorite which are pale green by transmitted light, and deep purple by reflected light Ozocerite and some petroleums also exhibit the property

Electric, Magnetic, and Thermic Properties

Electricity —Friction, pressure, and heat may all excite electricity in minerals To observe this property delicate electroscopes are required formed of a light needle terminating at both ends in small balls, and suspended horizontally on a steel pivot by an agate cup Such an instrument, can be electrified negatively by touching it with a stick of sealing wax excited by rubbing, or positively by merely bringing the wax so near as to attract the needle When the instrument is in this state, the mineral, if also rendered electric by heat or friction, will attract or repel the needle according as it has acquired electricity of an opposite or of a similar kind, but if the mineral is not electric it will attract the needle in both conditions alike

Most precious stones become electric from friction and are either positive or negative according as their surface is smooth or rough All gems become positive when polished the diamond even when unpolished is positive Pressure between the fingers will excite distinct positive electricity in pieces of transparent double refracting calc spar Topaz aragonite fluor spar carbonate of lead quartz, and other minerals show this property, but in a much smaller degree Some bodies remain excited much longer than others, topaz for a very long time Heat or change of temperature excites electricity in many crystals, as in tourmaline calamine topaz, calc spar beryl barytes fluor spar diamond garnet, and others, these are hence said to be thermo or pyro electric Some acquire polar pyro electricity or the two electricities appear in opposite parts of the crystal which are named its electric poles Each pole is alternately positive and negative the one when the mineral is heating, the other when it is cooling Hankel s investigations of these phenomena are specially noteworthy

As already noticed many polar electric minerals are also remarkable for their hemimorphic crystal forms Tourmaline, calamine and boracite are among the species thus affected The polarity continues so long as the temperature is increasing and becomes reversed when it commences to decline and when the heat is stationary it disappears

Rose and Riess name one of the poles the analogue electric pole, and the other the antilogue electric pole The former becomes positive while the crystal is heating and negative while cooling the latter negative while heating and positive while cooling Becquerel found that in tourmaline at 30 C electrical polarity was sensible it continued unchanged to 150° as long as the temperature continued to rise, if the temperature remained stationary an instant the polarity disappeared, but shortly manifested itself reversed, when the temperature commenced to decline If but one end of the crystal was heated the crystal was unpolarized and when two sides were unequally heated each acquired an electrical state independent of the other In tourmaline the extremities of the prism are dissimilarly modified, and that end which presents the greater number of planes is the antilogue pole, or, if the number of planes is the same, the secondary rhombohedrons of the antilogue pole have (one or more of them) longer vertical axes than those of the analogue pole Fig 249 (tourmaline) is the antilogue pole (negative under increasing heat), and fig 250 the analogue pole The pyramid of the analogue end is more flattened by its facets than that of the antilogue end, thus e^3 and $d^{\frac{3}{2}}$ of the antilogue end are more acuminating than e^1 and d^2 of the analogue end The same is the case with the other two crystals (figs 251, 252)

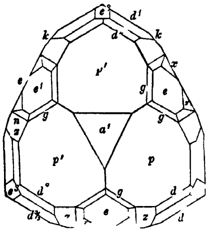


Fig 249

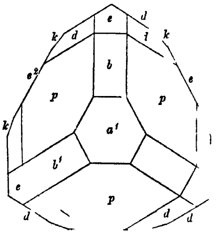


Fig 250

Pyro electricity has been observed in the following substances — tourmaline, topaz, axinite, boracite, scolezite, prehnite, electric calamine, sphene, rhodizite, heavy spar, rock crystal

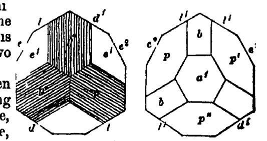


Fig 251

Pyro electricity is of two kinds,—either terminally polar or centrally polar In the former the extremities are opposite poles In the latter two sides of a prism are of the same name, and the opposite pole to each is intermediate between the two

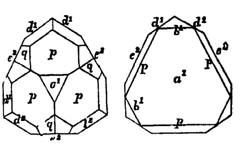


Fig 252

The examples of the first kind are tourmaline, calamine, and scolezite, which are uniaxal axinite, binaxal boracite and rhodizite, with four axes Calamine, like tourmaline, has the sharper extremity the antilogue end, and the more flattened the analogue Compound crystals from Altenberg have both ends analogue, and the portion which lies between the twins antilogue electric, the pyro electric axis corresponds with the vertical axis of the prism, as in tourmaline Boracite, which crystallizes in cubic forms, with the opposite solid angles differently modified, has four pyro electric axes corresponding to the four octahedral axes In fig 253 of this species, the plane which has its angles modified by *i* is the antilogue pole, and that with the unmodified angles the analogue pole, and, generally, the antilogue pole has either more numerous or larger facets Rhodizite resembles boracite in its pyro electricity

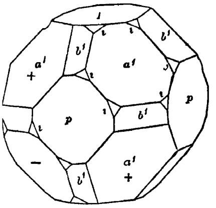


Fig 253

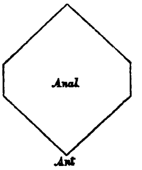


Fig 254

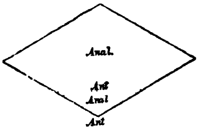


Fig 255

The species in which pyro electricity of the second kind has been observed are prehnite and topaz If fig 254 represent a tabular crystal of prehnite, the poles will be situated as marked, the analogue being central, and the antilogue at either extremity of the shorter diagonal of the rhombic prism Topaz has in a similar manner a central analogue pole, and an antilogue at either extremity of the shorter diagonal In some instances there is a separate set of similar poles near one or the other angle as in fig 255, this must be due to the crystals being of a composite nature

Magnetism —This property is very characteristic of the few minerals in which it occurs,—chiefly ores of iron or nickel Some magnetic iron ores possess polar magnetism, or are natural magnets, while the common varieties of magnetite, meteoric iron, magnetic pyrites, precious garnet, and other minerals, are simply magnetic Most minerals are only attracted by the magnet, but do not themselves attract iron

Minerals, as other substances, have also been divided into magnetic and diamagnetic See MAGNETISM

The ordinary mode of testing whether a mineral is magnetic or not is to bring it near a pole of a delicately suspended magnetic needle, and observe whether it causes it to vibrate. Another mode is to apply a strong magnet to the mineral in powder. These are sufficient for the mineralogist. Delesse has experimented extensively upon the magnetic force of minerals, and has determined the relative amount for numerous species. Calling this force for Styrian steel 100, the following are some of his results:—

Native platinum	
Magnetic iron ore	
Franklinite from the United States	
Chromic iron	0 136 to 0 065
Spinel (pleonaste) from Monzoni, Tyrol	0 078
Titanic iron (rhombohedral) often magnetipolar	5 64
Specular iron sometimes magnetipolar	0 14 to 2 35
Graphite	0 015 to 0 040
Spathic iron (spherosiderite the highest)	0 092 to 0 87
Iron pyrites	0 0 9 to 0 057
Vivianite	0 027 to 0 0 5
Columbite of Bodenmais and Haddam	0 1 1
Pyrochlore	0 010
Chrysoprase (quartz is diamagnetic but many varieties are magnetic)	0 004
Felspar sometimes feebly magnetic	
Labradorite of an antique green porphyry	0 077
Hornblende	0 012 to 0 0 7

Magnetic polarity.

Crystallomagnetic Action.—The magnetic polarity thus far alluded to belongs to the mass, and has no relation to crystalline form. There is also a kind of polarity directly related to the crystalline or optic axes of minerals. A crystal of cyanite, suspended horizontally, points to the north, by the magnetic power of the earth only, and is a true compass needle, from which even the declination may be obtained; and the line of direction is the line of the optic axes. Other crystals, which are called negative, take a transverse or equatorial position. The latter are diamagnetic crystals.

Heat conductivity.

Conductivity for Heat.—Senarmont found that the conducting power of colloids and of crystals of the cubic system is equal in all directions, but that it varies in different directions in crystals belonging to all the other systems, exhibiting characters analogous to those deduced from their double refraction, conformable with the optic axes of the crystal, and referable, as in the latter case, to axes of elasticity, or unequal compression of the molecules.

The fundamental fact is easily shown by taking two slices of rock crystal, one cut transverse to the axis and one parallel to it. Through the centre of each plate a small hole is drilled for the reception of a bent wire which by insertion into the hole sustains the plate. The other end of the wire is to be heated, and the rate of the conduction of the heat is rendered visible by the amount of a thin coating of beeswax with which the plate has been previously coated, which is melted round the central hole. It will be seen that in the transverse slice the wax is melted in a circular form, while in the longitudinal slice the form is elliptical (fig 256). The conduction is equal in all directions, as regards the transverse axes of the hexagonal prism, but more rapid in one direction in the longitudinal slice, and that direction is the line of its optic axis. In the case of quartz the two diameters of the ellipse are as 1000 to 1312.

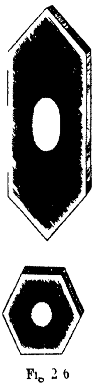


Fig. 256

If the regular disposition of the molecules of amorphous bodies be interfered with by unequal tension or compression, the regularity of their power of conducting heat is destroyed, and they also show elliptical forms of melted wax, and the shorter axis of the ellipse is in the line of pressure or undue packing of the molecules. The heat thus does not travel so fast in this direction,—partly because it is spent in the heating up of the greater number of molecules. Hence we might conclude that along the main axis of quartz a smaller number of molecules are packed in an equal space than along the transverse. The following are the more important of Senarmont's results.

Senarmont's investigations.

1 Crystals of the tetragonal and rhombohedral systems have one axis of conductivity which is either greater or smaller than the others, and this axis coincides with the main crystallographic axis. The isothermal surfaces are ellipses which lie in the line of this axis, and these ellipses may be either elongated or flattened in the direction of this line.

2 In crystals of the right prismatic system the isothermal surfaces have three unequal axes, which coincide with crystallographic axes drawn parallel to the edges of the rectangular prism.

3 In crystals of the oblique rhombic system the isothermal surfaces have three unequal axes, one of which coincides with the horizontal diagonal of the base, while the other two have directions which are not referable to any law.

4 In crystals of the anorthic system the isothermal surfaces have three unequal axes, all with indeterminable positions.

In crystals of a single axis there appears to exist no constant relation between the axis of optic elasticity, whether maximum or minimum, and the axis of the greatest or of the least calorific conductibility. Thus, of the minerals examined by Senarmont, quartz (+), calcite (−), cassiterite (+), rutile (+), and calomel (+) have all their greatest axis of conductibility parallel to the principal axis; idocrase, beryl, tourmaline and corundum, all optically negative, have on the contrary their smallest axis of conductibility parallel to the axis.

In crystals belonging to the oblique rhombic system there is rarely coincidence between the thermic axes and the axes of optic elasticity. In gypsum and in felspar these lie apart to a marked extent.

Dilatation.

Dilatation by Heat.—In crystals of those systems in which the molecules are arranged unequally as regards their axes, the amount of their dilatation when heated is unequal in the direction of their axes. Our knowledge of this subject is chiefly due to Mitscherlich.

In crystals of cubic symmetry the expansion is equal in all directions. The dimetric systems—the pyramidal and hexagonal—are brought together as regards this quality, inasmuch as the axes of volumetric change are in these the same; for, while these in the pyramidal correspond with the crystallographic axes, in the hexagonal the three axes are the vertical, one lateral axis, and an axis lying intermediate to the other two and at right angles to the first lateral axis. The expansion along the principal axis may be either greater or less than along the others, and in some minerals there is even contraction along one axis.

In the right prismatic system the axes of dilatation correspond to those of form. In the oblique prismatic one axis corresponds with the orthodiagonal, but the others make angles not only with the other crystallographic axes but, strange to say, with the axes both of thermic conductivity and of optic elasticity. We are as yet ignorant of the properties of anorthic crystals in this respect.

As a consequence of this unequal expansion along different axes, the angles of crystals, other than those of the cubic system, are altered under the influence of heat. The alteration is extreme in the case of calcite, where, through elongation along the vertical axis with some concomitant contraction of the transverse, the angle of the rhombohedric faces is, when the crystal is heated from 32° to 212° F, diminished from 105° 5′ to 104° 56′ 23″,—the form thus approaching that of a cube as the temperature is raised.

Dolomite in the same range of temperature diminishes 4′ 46″. In some rhombohedrons as of calc spar the vertical axis is lengthened (and the lateral shortened), while in others like quartz the reverse is true. The variation is such, either way, that the double refraction is diminished with the increase of heat; for calc spar possesses negative double refraction, and quartz positive. According to Fresnel the same is true of gypsum. The dilatation for calc spar, according to experiment, is 0 001961.

Kopp has shown that in the carbonates of lime, magnesia, iron, manganese, and zinc, which are nearly the same in the angle of their crystals, the vertical axis is shorter the greater the atomic volume. And since heat diminishes the density, and therefore necessarily increases the volume, the axis *a* should be lengthened by an increase of temperature, as is actually the case. He has determined by calculation that the change of angle from 32° to 212° should be 7′ 37″.

Although in the greater number of cases the variations are so small as to be scarcely measurable, yet they may be sufficient for establishing a difference between substances which have identical geometric form while belonging to different systems of crystallization. The angle of a rhombohedron might at a certain temperature be 90°, and so coincide with a cube; but that angle would in a rhombohedron change whenever the temperature altered, while the angle of a true monometric cube is constant at all temperatures. The increase in volume and diminution in density which generally result from heating are always accompanied by a change in optical properties. In trimetric crystals, where the principal indices alter unequally, the change affects the amount of divergence of the optic axes. The amount of alteration in gypsum, when the divergence is diminished, is extreme. At the ordinary temperature the angle of the divergence of the optic axes which lie in the plane of symmetry is about 90° for red light; when heated to 1[illegible]7° it is diminished to 0°, and for the moment the crystal appears to be uniaxal. When more highly heated, the axes again diverge, but in a plane at right angles to the original one, and in cooling these changes take place in reverse order. In barytes and celestine again, the alteration in the angle of the optic axes is a divergence when heated.

Characters depending on Cohesion

These characters are of five kinds —(1) hardness, (2) tenacity, (3) elasticity, (4) cleavage, (5) fracture All may be considered as related to the power of resisting attempts to separate one part from another

1 *Hardness* —A harder body is distinguished from a softer either by attempting to scratch the one with the other or by trying each with a file Each of these methods is used by the mineralogist in determining the hardness of the species, though the latter is in most cases to be preferred Both methods should be employed when practicable

Certain varieties of some minerals give a low hardness under the file owing either to impurities or imperfect aggregation of the particles while they scratch another mineral upon which a file would have no effect showing that the particles of the first are hard, though loosely aggregated Chiastolite, spinel, and sapphire are common examples of this When the mineral is too hard to be impressed by a file the peculiarity of the grating sound will suffice for the practised ear

Mohs introduced a scale of hardness, consisting of ten minerals, which gradually increase in hardness from 1 to 10 The intervals between 2 and 3 and 5 and 6 are larger than the others Breithaupt has therefore introduced another degree of hardness between each of the above, and thus his scale consists of twelve minerals

The scale is as follows —

1 Talc common laminated light green variety
2 Gypsum a crystallized variety
2 5 Mica (muscovite)
3 Calcite transparent variety
4 Fluor spar crystalline variety
5 Apatite transparent variety
5 Scapolite crystalline variety
6 Felspar (orthoclase), white cleavable variety
7 Quartz transparent
8 Topaz transparent
9 Sapphire cleavable varieties
10 Diamond

If the file abrades the mineral under trial with the same ease as No 4 and produces an equal depth of abrasion with the same force, its hardness is said to be 4, if with more facility than 4 but less than 5 the hardness may be $4\frac{1}{4}$ or $4\frac{1}{2}$ written in decimals 4 25 4 5 Several successive trials should be made to obtain certain results

The use of the file is acquired with very little experience usually a single trial is sufficient Care must be taken to apply the file to edges of equal obtuseness That part also of the specimen should be selected which has not been altered by exposure, and has the highest degree of transparency and compactness of structure The pressure for determination should be rather heavy and the file should be passed three or four times over the specimen

Where the scale of hardness is wanting or a first rough determination is sought the following experiments may serve —

Every mineral that is scratched by the finger nail has H = 2 5 or less Minerals that scratch copper have H = 3 or more Polished white iron has H = 4 5 Window glass has H = 5 to 5 5 Steel point or file has H = 6 to 7 hence every mineral that will cut or scratch with a good penknife has H less than 6 Flint has H = 7, and only about a dozen minerals including the precious stones or gems, are harder

Many specimens present different degrees of hardness on dissimilar faces as an example of which we mention cyanite and mica This is confined to the inequilateral primary forms and like the similar difference of colour, lustre &c, finds a ready explanation in the theory of their formation, unlike faces are the result of the action of a polar force acting along unlike axes

This difference in faces parallel to unlike axes may be perceived in nearly all cases when the methods of trial are sufficiently delicate Huygens observed long ago that the cleavage face of a crystal of calc spar differed in hardness from the other faces and even in a monometric crystal it has been found that the faces of the cube and octahedron are not exactly alike in this respect

Tenacity

2 *Tenacity* —Solid minerals are said to be brittle, sectile, malleable, flexible, or elastic —

1 *Brittle* when parts of a mineral separate in powder or grains on attempting to cut it, as baryte calc spar

2 *Sectile* when pieces may be cut off with a knife without falling to powder but still the mineral pulverizes under a hammer, as brucite gypsum

3 *Malleable* when slices may be cut off and these slices flatten out under a hammer, as native gold native copper

4 *Flexible* when the mineral will bend and remain bent after the bending force is removed, as gypsum, graphite, talc

5 *Elastic*, when after being bent it will spring back to its original position, as mica

A liquid is said to be *viscous* when, on pouring it, the drops lengthen and appear ropy, as petroleum

Elasticity.

3 *Elasticity* —Investigations on this property have not to any extent been entered upon The unequal elasticity of unlike faces of crystals has been shown by Savart in his acoustic investigations, and he was able to distinguish the rhombohedral from the other faces in the pyramid of quartz crystals, he also showed that the figures formed upon vibrating plates of crystals were directly connected with their optic axes Milne, by measuring the amount of recoil of a sphere of calcite when struck at different points by another of rock crystal, found that the elasticity, as thus measured, was greatest along the line of the optic axis, and least in directions at right angles to it He also found that points which lay intermediate between the main and the transverse axes were most indented by the blows This goes to show that, although there may be fewest molecules arranged along the lines of the transverse axes, yet cohesion operates with greater intensity along these than in intermediate directions

When the tenacity of a mineral is overcome by an overwhelming amount of traction, or its elasticity by a sudden shock, its parts are separated, either in flat and continuous surfaces, or in surfaces which are irregular in the extreme The first of these modes is termed cleavage, the second fracture In those substances in which cleavage exists it is found that the planes or directions along which it takes place lie in certain strictly definite positions to one another and to the axes of the crystal They show not the smallest tendency to a transition or gradual passage into the other directions of greater coherence

Cleavage.

4 *Cleavage* —The number of these parallel cleavage planes is altogether indefinite, so that the only limit that can be assigned to the divisibility of some minerals, as gypsum and mica, arises from the coarseness of our instruments These minima of coherence, or cleavage planes, are always parallel to some face of the crystal, and similar equal minima occur parallel to every other face of the same form Hence they are always equal in number to the faces of the form, and the figures produced by cleavage agree in every point with true crystals, except that they are artificial They are thus most simply and conveniently described by the same terms and signs as the faces of crystals

Some minerals cleave in several directions parallel to the faces of different forms, but the cleavage is generally more easily obtained and more perfect in one direction than in the others This complex cleavage is well seen in calc spar and fluor spar, and very remarkably in zinc blende, where it takes place in no less than six directions As in each of these the division may be indefinitely continued, it is clear that no lamellar structure in any proper sense can be assigned to the mineral All that can be affirmed is that contiguous atoms have less coherence along a direction normal to these planes than in other directions When cleavage takes place in three directions, it of course produces a perfect crystal form, from which the system of crystallization and angular dimensions of the species may be determined, it is thus often of very great importance

The common cleavage in the different systems is as follows, those of most frequent occurrence being in italics —(1) In the cubic system, *Octahedral*, O, along the faces of the octahedron, *Hexahedral*, $\infty O\infty$, along those of the cube, and Dodecahedral, ∞O (2) In the tetragonal system, Pyramidal, P, or $2P\infty$, *Prismatic*, ∞P, or $\infty P\infty$; or *Basal*, $0P$ (3) In the hexagonal system with holohedral forms, Pyramidal, P, or P2, *Prismatic*, ∞P, or $\infty P\infty$, or *Basal*, $0P$, with rhombohedral forms, *Rhombohedral* R, Prismatic ∞R or *Basal*, $0R$ (4) In the right prismatic system, Pyramidal, P, *Prismatic*, ∞P, Macrodomatic or Brachydomatic, $\bar{P}\infty$ or $\breve{P}\infty$, *Basal*, $0P$, Macrodiagonal, $\infty\bar{P}\infty$, or *Brachydiagonal*, $\infty\breve{P}\infty$ (5) In the oblique prismatic system, Hemipyramidal, P, or $-P$, *Prismatic*, ∞P, Clinodomatic, $P^{c}\infty$, Hemidomatic, $P^{o}\infty$ or $-P^{o}\infty$, *Basal*, $0P$, Orthodiagonal, $\infty P^{o}\infty$ or *Clinodiagonal*, $\infty P^{c}\infty$ (6) In the anorthic system, Hemiprismatic, $\infty P'$, or $\infty{}'P$, Hemidomatic either along the macrodome or the brachydome *Basal*, 0P, Macrodiagonal, $\infty \bar{P} \infty$, or *Brachydiagonal*, $\infty \breve{P} \infty$

In some minerals, as mica and gypsum, the cleavage is readily procured, these may be held in the hand and divided by a knife Others only cleave with more or less difficulty, these must be placed on a firm support resting on lead, folded paper, or cloth, and a sharp blow struck on a chisel applied in a proper direction This may often be ascertained by examining the specimen in a strong light Sometimes it is necessary to subject them to extreme compression in a vice Some of the hardest substances have not only a perfect but a facile cleavage,—as euclase, topaz, and diamond, many of the softest species have none The planes produced also vary much in their degree of perfection, being highly perfect in some, as mica and calc spar, and imperfect in others, as garnet and quartz In a very few crystalline minerals cleavage planes can hardly be said to exist Cleavage must be carefully distinguished from the planes of union in twin crystals, and the division planes of laminar minerals

Fracture 5 *Fracture*—This is the irregular manner in which substances may be broken Even minerals possessed of cleavage may be fractured in other directions, but in amorphous bodies fracture alone occurs The following varieties of fracture occur, and are highly characteristic —

1 *Conchoidal* almost typical of amorphous bodies, but occasionally seen in crystals —rounded cavities more or less deep The name is taken from the resemblance to the successive lines of interrupted growth in a bivalve shell Seen in flint obsidian, asphalt In calcite the direction of this fracture is intermediate to the planes of the mineral s cleavage

2 *Even* when the surface of fracture is smooth and free from inequalities

3 *Rough* when the surface of fracture is rugged, with numerous small elevations and depressions

4 *Splintery*, when covered with small wedge shaped splinters

5 *Hackly* when the elevations are sharp, slightly bent, or jagged as broken iron

6 *Earthy* when it shows only fine dust

Taste, Odour, Touch

Taste. *Taste* belongs only to soluble minerals The different kinds adopted for reference are as follows —

1 *Astringent* the taste of blue vitriol
2 *Sweetish astringent* taste of alum
3 *Saline* taste of common salt
4 *Alkaline*, taste of soda
5 *Cooling* taste of saltpetre
6 *Bitter*, taste of epsom salts
7 *Sour*, taste of sulphuric acid
8 *Pungent*, taste of sal ammoniac
9 *Metallic*, taste of zinc sulphate

Odour. *Odour*—Excepting a few gaseous and soluble species, minerals in the dry unchanged state do not give off odour By friction, moistening with the breath, and the elimination of some volatile ingredient by heat or acids, odours are sometimes obtained which are thus designated —

1 *Alliaceous*, the odour of garlic Friction of arsenical iron elicits this odour it may also be obtained from any of the arsenical ores or salts by means of heat

2 *Horse radish odour* the odour of decaying horse radish This odour is strongly perceived when the ores of selenium are heated

3 *Sulphurous* Friction will elicit this odour from pyrites, and heat from many sulphurets

4 *Bituminous* the odour of bitumen

5 *Fetid* the odour of sulphuretted hydrogen or rotten eggs It is elicited by friction from some varieties of quartz and limestone

6 *Argillaceous*, the odour of moistened clay It is obtained from serpentine and some allied minerals after moistening them with the breath, others as pyrargillite, afford it when heated

7 *Empyreumatic* or *ozonic* Quartz, when two portions strike one another

Touch—Some minerals are distinguished by a greasy feeling as talc, others feel smooth, as celedonite, others meagre, like clay, others cold This last character distinguishes true gems from their imitations in glass Some, in virtue of their hygroscopic nature, adhere to the tongue

CHEMICAL PROPERTIES OF MINERALS

Relation of composition to physical properties *Influence of Chemical Composition on the External Characters of Minerals*—That the characters of a compound must to a certain extent depend on those of its component elements seems, as a general proposition, to admit of no doubt Hence it might be supposed possible from a knowledge of the composition of a mineral to draw conclusions in reference to its form and its other properties, but practically this has not yet been effected

The distinction between the mineralizing and mineralizable or the forming and formed elements lies at the foundation of all such inquiries Certain elements in a compound apparently exert more than an equal share of influence in determining its physical properties Thus the more important non metallic elements as oxygen, sulphur, chlorine, fluorine, are remarkable for the influence they exert on the character of the compound The sulphurets for example, have more similarity among themselves than the various compounds of one and the same metal with the non metallic bodies Still more generally it would appear that the electro negative element in the compound is the most influential or exerts the greatest degree of active forming power After the non metallic elements the brittle, easily fusible metals rank next in power then the ductile ignoble metals, then the noble metals, then the brittle, difficultly fusible, and, last of all the metals of the earths and alkalies

Generally each chemical substance crystallizes only in one form or series of forms Some substances, however, show dimorphism, or crystallize in two forms and thus may compose two or more minerals Thus sulphur, which in nature usually crystallizes in the right prismatic system when melted forms oblique prismatic crystals Carbon in one form is the diamond in another graphite carbonate of lime appears as calc spar and as aragonite the bisulphuret of iron as pyrite and as marcasite An example of trimorphism occurs in titanic acid forming the three distinct species anatase rutile, and brookite It is remarkable that of dimorphic minerals one form is almost always right prismatic, thus —

	Rhombic Form
Cyanite anorthic	Sillimanite Andalusite
Calc spar hexagonal	Aragonite
Susannite do	Leadhillite
Rutile pyr	Brookite
Pyrolusite right prismatic	Polianite
Cuprite cubic	Chalcotrichite (?)
Senarmontite cubic	Valentinite
Pyrite do	Marcasite
Rammelsbergite do	Chloanthite
Argentite do	Acanthite
Freieslebenite oblique prismatic	Diaphorite
Sulphur do	Sulphur

Even the temperature at which a substance crystallizes influences its forms and so far its composition, as seen in aragonite Glauber salt natron, and borax

Isomorphism. *Isomorphism*—Still more important is the doctrine of isomorphism, designating the fact that two or more simple or compound substances crystallize in one and the same form, or often in forms which, though not identical, yet approximate very closely This similarity of form is generally combined with a similarity in other physical and in chemical properties Among minerals that crystallize in the tesseral system, isomorphism is of course common and perfect, there being no diversity in the dimensions of the primary form, but for this very reason it is generally of less interest It is of more importance among crystals of the other systems, the various series of which are separated from each other by differences in the proportions of the primary form In these perfect identity is seldom observed, but only very great similarity

The more important isomorphic substances are either simple substances, as (1) fluorine and chlorine (2) sulphur and selenium, (3) arsenic, antimony, (4) cobalt, iron, nickel, (5) copper, silver, mercury, gold (?), or combinations with oxygen as (6) lime, magnesia, and the protoxides of iron, manganese, zinc (7 sesquioxides, as of iron, manganese, chromium and alumina (8) phosphoric acid, vanadic acid, arsenic acid (9) sulphuric selenic, chromic acids, or combinations with sulphur, as (10) sulphuret of iron and of zinc, (11) sulphuret of antimony and of arsenic (12) sulphuret of lead, of copper, and of silver These substances are named vicarious from the singular property that in chemical compounds they can mutually replace each other in definite proportions, and very often without producing any important change in the form or other physical properties But there are numerous instances among the silicates where the mutual replacement of the isomorphic bodies, especially when the oxides of the heavy metals come in the room of the earths and alkalies exerts a most essential influence on the external aspect of the species particularly in regard to colour, specific gravity, and transparency The varieties of hornblende, augite, garnet epidote and many other minerals are remarkable proofs of this influence This intermixture of isomorphic elements confers many valuable properties on minerals, and to it this department of nature owes much of its variety and beauty Without the occasional presence of the colouring substances, especially the oxides of iron and manganese the non metallic combinations would have exhibited a very monotonous aspect It is also remarkable that in some silicates the substitution of a certain portion of the metallic oxides for the earthy bases seems to be almost a regular occurrence, whilst in others, as the felspars and zeolites this rarely happens This fact is also of great economic interest as drawing attention to important elements often combined with others of less value Thus iron oxide and chrome oxide, sulphuret of copper and sulphuret of silver, nickel and cobalt, may be looked for in connexion The general chemical formulæ for such compounds is formed by writing R (= radical or basis) for the whole isomorphic elements, and in special instances their signs are placed one below the other, connected by a bracket, or, as is more convenient, are enclosed in brackets one after the other separated by a comma Thus the general sign for the garnet is $R_3\,Si_2 + \bar{R}\,Si$, which, when fully expressed, becomes $(Ca_3, Fe_3, Mg_3, Mn_3)\,Si_2 + (\bar{Al}, \bar{Fe}, \bar{Cr})\,Si$, and this mineral forms many varieties as the one or other element preponderates

Of the forms special to similar groups of atoms the more notable are—the cubic system, special to metals proper, and binary compounds as protoxides and haloid salts, the tetragonal to binoxides, the rhombohedral to carbonates, the hexagonal to sesquioxides and phosphates and their isomorphs, the prismatic to sulphates and their isomorphs

The isomorphism of minerals goes as a whole to show that form depends on the number of molecules present, and is comparatively little influenced by the nature of the molecules themselves

DESCRIPTION OF MINERAL SPECIES

The arrangement adopted in the following description of mineral species is chemical Simple substances are considered first, in the order of their quantivalence, then binary compounds, and lastly those of more complex structure Our limits permit of the briefest notice of the less important, in order that more space may be available for the delineation of the characteristic and transition forms of such as go to constitute the more important rock masses

The following abbreviations are used —H, hardness, G, specific gravity (distilled water at 60° Fahr and barometer 30 inches = 1), cl, cleavage, sol, soluble, s [h or n] acid, sulphuric [hydrochloric or nitric] acid, B B, before blowpipe, ox, oxidizing, red, reducing, c c, chemical composition, com, combination

In the chemical formulæ, barred letters express two equivalents, and the dots over the symbols indicate the combination with them of as many equivalents of oxygen as there are dots

In the symbolic notation the several faces of crystals are separated by semicolons, and the constituent members of combinations by commas The lettering on the faces of the figures is for the most part that adopted by Miller In the enumeration of crystal forms, that which is typical of the mineral is placed first

SIMPLE SUBSTANCES

1 Sulphur, S

Bi valent elements

(*a*) Right prismatic P (*p*) polar edges 106° 38, 84° 58, middle edge 143° 17 ∞P 101° 58, 0P (*c*), ⅓P (*s*), P̆∞ (*n*) Crystals pyramidal, single or in druses, also stalactitic, disseminated, and pulverulent Cl basal and ∞P H = 1 5 to 2 5, G = 1 9 to 2 1 Fracture conchoidal or splintery, brittle sectile Lustre resinous, streak and colour sulphur yellow passing into red, brown, or green Sublimes in the closed tube Fuses a little above the temperature of boiling water Takes fire at 518° F, and burns with a pale blue flame with odour of sulphurous acid C c pure sulphur, occasionally mixed with traces of selenium, and when amorphous with clay or bitumen Found chiefly in Tertiary strata Localities Girgenti in Sicily with celestine Conil in Spain, Bex in Switzerland Cracow in Poland, deposited from hot springs in Solfatara near Naples, from hot springs in Iceland from sulphur springs in New York, and in cavities of decomposing galena, cinnabar, and pyrites at several localities

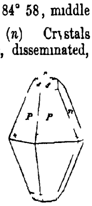


Fig 257

(*b*) Oblique prismatic The crystals of volcanic sulphur are of this form, they occur in the neighbourhood both of extinct and of recent volcanoes They are slender needle shaped, and interlacing, and have generally more or less of a red brown tinge Oxhaveer and Cape Reykjanes in Iceland, Sicily and the volcanoes of the Pacific, the Chilian Andes, and California yield this variety

2 Selensulphur, S Se

Like sulphur, but reddish brown to orange yellow B B burns with fumes of selenious acid mixed with the sulphurous Found in the crater of Volcano in the Lipari Islands, and Kilauea in Hawaii

3 Selenium, Se

H = 2, G = 4 3 Brownish black to lead grey, thin splinters translucent and red From Culebras in Mexico

4 Tellurium, Te

Rhombohedral, R 86° 50′ In minute hexagonal prisms, with basal edges replaced, usually massive and granular Cl lateral perfect, basal imperfect H = 2 to 2 5, G = 6 1 to 6 3 Tin white, sectile C c tellurium with a little gold and iron Occurs at Facsebaya near Zalathna (Transylvania), and in several mines in Boulder county, Colorado, masses 25 ℔ in weight have been obtained there

5 Arsenic, As

Tri-valent elements

Rhombohedral, R 85° 36′ (fig 258) Usually in botryoidal investing masses composed of numberless layers The structure is fine granular, rarely columnar H = 3 5, G = 5 7 to 5 93 Cl basal Colour black and dull, but when fresh broken very splendent and silver white, fracture uneven When rubbed or heated gives out a garlic like odour B B volatile, with formation of white fumes C c arsenic, with some antimony, and traces of iron, silver, and gold Andreasberg in the Harz, Annaberg, Schneeberg Freiberg, Joachimsthal, Allemont (Dauphiné), Kongsberg (Norway), the Altai, Chili, Pebble mine (Dumfriesshire), Tyndrum (Perthshire)

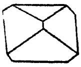


Fig 258

6 Antimony, Sb

Rhombohedral, R 87° 35′, but rarely crystallized, generally in foliated or granular masses Cl basal H = 3 G = 6 6 to 6 8 Tin-white, with slight yellow tarnish Brittle and sectile B B easily fusible, volatilizes, and on charcoal leaves a white deposit burning with a pale flame Found at Andreasberg, Przibram (Bohemia), Sala (Sweden), Allemont, Southham in East Canada, and Borneo

7 Allemontite, $SbAs_3$.

Hexagonal, spherical, reniform, and investing H = 3 5 G = 6 1 6 2 Lustre, when fresh, metallic Tin white to lead grey, but with a blue or brown tarnish B B strong odour of garlic, with residuum of oxide of antimony C c antimony 37 85 arsenic 62 15 Almost always in curved foliated laminæ Occurs at Allemont, Przibram, Schladming in Styria, Andreasberg

8 Bismuth, Bi

Rhombohedral, R 87° 40′ Crystals, R, 0R, generally distorted, also reticulated, spear head twins, or arborescent, also disseminated and granular Cl basal, perfect H = 2 5 G = 9 6 to 9 8 Brittle and sectile Reddish white, often tarnished grey brown, or blue. B B easily fusible, even in candle flame Volatilizes on charcoal, leaving a citron yellow crust Sol in n acid solution precipitated when thrown into water Occurs in gneiss and clay slate in veins and disseminated, along with ores of cobalt, silver, lead, and zinc Alva in Stirlingshire, Cumberland, Devonshire and Cornwall, Schneeberg, Marienberg, Joachimsthal, Bieber, Modum (Norway), Falun (Sweden), Bolivia

9 Telluric Bismuth, Bi_2Te_3

Bismuth 52, tellurium 48 Virginia, Dahlonega in Georgia, Montana A variety with 7 per cent of selenium and H = 2 also occurs

10 Tetradymite, Bi_2Te_2S.

Rhombohedral, 3R 68° 10. Almost always twins of 3R and 0R, with the faces of 0R at 93° Cl basal, perfect Sectile and thin laminæ flexible H = 1 to 2, G = 7 2 to 7 5 Steel grey B B. fuses, yielding a grain of metal which ultimately volatilizes Sol. in n acid C c 59 6 bismuth, 35 9 tellurium, and 4 5 sulphur. Schemnitz

11 WEHRLITE, $Bi(Te_2S)$

Hexagonal Cl basal H = 1 to 2, G = 8 44 High lustre Steel-grey C c bismuth 61 15, tellurium 29 74, sulphur 2 33, silver 2 07 Deutsch Pilsen in Hungary

12 JOSFITE, $Bi_3Te_2(SSe)_2$

Hexagonal Cl basal G = 7 93 Colour grey black to steel grey Brittle C c tellurium 15 93, sulphur 3 15, selenium 1 48, bismuth 79 15 San Jose (Brazil) A Cumberland variety yielded tellurium 6 73, sulphur 6 43, bismuth 84 33, corresponding to $Bi_4(TeS_4)$

13 DIAMOND, C

Quadrivalent elements.

Var 1 *Crystallized*—Cubic, very frequently hemihedral Crystals most generally with curved faces Twins common on the octahedral face, hemitropes also common (see figs 170, 204 205, 207) Crystals vary remarkably in appearance (see figs 259 to 262) Cl octahedral H = 10, G = 3 5 to 3 6 Transparent, or translucent when of dark colour Refracts light strongly The back planes of diamonds reflect all the light which strikes them at an angle exceeding 24° 13, and thence comes their peculiar brilliancy High adamantine lustre Colourless but often tinged white, grey, and brown,—more rarely yellow, pink, blue, green and black, those last named being the rarest Disperses light highly and hence emits brilliant flashes of all the colours of the spectrum Becomes positively electric by friction B B infusible, but burns into carbonic acid in oxygen gas When air is excluded is unchanged at the temperature of melting cast iron, but at that of melting malleable iron is changed into a black coke, or it is said, into graphite Insoluble in all acids and alkalies C c carbon with traces of silica and earths Geologic formation apparently a laminated flexible quartz rock called itacolumite which occurs in Brazil the Urals, Georgia and North Carolina, in the vicinity of places where diamonds have been found Minute crystals have been found in xanthophyllite, and in talc slate and serpentine in the Schischimskian hills near Zlatoust (Russia) They have also been obtained in Brazil imbedded in a conglomerate composed of much worn pebbles of quartz, chalcedony, and gold, cemented by limonite or ferruginous clay In South Africa they are imbedded in a steatitic clay Diamonds were formerly obtained in India at Panna Raolconda and Golconda So few are now obtained here that the mines are let for £1 a year From these mines were obtained not only the Kohinoor which was possibly the same as the great diamond mentioned by Tavernier as having been seen by him in the possession of the Great Mogul, which weighed 280 carats but the Regent of 136 carats (which, not only from its size but from the perfection of its form, is very much the finest diamond known), the Nizam, an uncut diamond of 340 carats, and the Carlow rose cut, 193 carats More lately diamonds were found in great quantity in the neighbourhood of Rio Janeiro in Brazil they occur in two different deposits the one called "gurgulho consists of broken quartz covered by a bed of sand, the other, "cascalho consists of rolled quartz pebbles united by ferruginous clay both rest on talcose clays which are the debris from talcose rocks The first deposit affords the finest diamonds, and both contain gold, platinum, magnetite and rutile A dodecahedral diamond of 257 carats was lately found at Bogagem in this district, this was reduced by cutting to an oblong brilliant of 125 carats, and is the second most valuable diamond,—the Kohinoor, now reduced to an imperfectly circular brilliant of 102 carats, occupying the third place The two coloured diamonds most worthy of note are a green diamond in the Dresden collection weighing 31 carats, which is a little deeper in tint than a beryl, and a blue diamond in the Hope collection, of 44 carats, as highly coloured as a sapphire, which it is by some considered to be Diamonds have lately been found in very large quantities, and some of great size, north of the Cape of Good Hope, these for the most part are of yellow colour and of very inferior value While a Brazilian cut brilliant of one carat is worth from £20 to £25, the value of the finest brilliants from the Cape is only from £3 to £4, and that of the yellow diamonds is from £2 to £2, 10s Apart from its employment as an ornamental stone, the diamond has an intrinsic value from its being utilized for cutting glass and for grinding and polishing other gems Of late years its usefulness has had a new application, it being employed for the drilling of rocks in tunnelling operations and in the boring of artesian wells A singular observation has resulted from these last methods of utilizing it namely, that the hardness of the African diamonds, as tested by the amount of their endurance, is markedly inferior to that of the Brazilian and Indian So much is this recognized that, while the bort, or minute crystals, of the latter command a price of 15s per carat, the African can be got for about 5s The cleavage of certain of the African diamonds is so eminent that even the heat of the hand causes some of them to fall in pieces Such diamonds, generally octahedra, may be recognized by a peculiar watery lustre, they are called plate diamonds The above facts give some ground for the supposition that there may be a slight difference in their composition, possibly that both may contain small, but different, quantities of hydrogen The circumstances under which diamonds have been formed are altogether unknown The fact of their being changed into a kind of coke at a very high temperature is an argument against their having been produced through the operation of heat, and it has long been known that an excess of carbon dissolved by molten cast iron crystallizes on cooling in the form of graphite, yet the only attempts to form diamonds deserving of being mentioned as having been attended with any measure of success are those in which sugar charcoal was dissolved in molten silver at the temperature only of melting steel There were thus obtained a few minute black and also colourless octahedral and cubo octahedral crystals with curved faces, mingled with a much larger amount of graphitoidal carbon

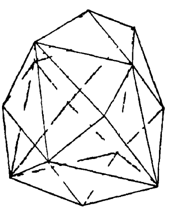


Fig 259

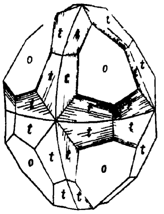


Fig 260

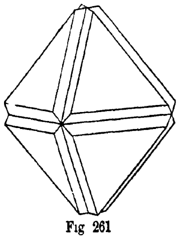


Fig 261

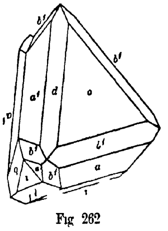


Fig 262

Var 2 *Massive*—In black pebbles or masses called *carbonado*, sometimes 1000 carats in weight H = 10 G = 3 012 to 3 42 C c carbon except 27 to 2 07 per cent of ash Found in the mines of Briranco &c in Bahia

Var 3 *Anthracitic*—Like anthracite, but scratches the diamond In mammillar masses partly in concentric layers, and globular Brittle G = 1 66 C c carbon 97, hydrogen 5, oxygen 1 5 When cut and polished, refracts and disperses light, like the diamond Supposed from Brazil

14 GRAPHITE, C

Hexagonal in flat crystals *p p* 85° 29 Usually foliated, scaly, or compact Cl basal H = 0 5 to 1 G = 1 9 to 2 2 Lustre metallic Colour and streak black to dark steel grey, flexible in thin laminæ, very sectile feels greasy, leaves a mark on paper of its own colour, conducts electricity B B burns with difficulty heated with nitre, deflagrates C c carbon, with small quantities of volatile matter and ash from 5 to 40 per cent Strathfarrer (Inverness shire) Mull Craigman (Ayrshire), Borrowdale in Cumberland, Ural Mountains, Ceylon, Greenland Used for making pencils

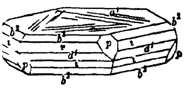


Fig 263

15 TIN, Sn

Tetragonal in greyish white metallic grains Reported as occurring with Siberian gold, with bismuthite from Guanajuato in Mexico

16 IRON, Fe

Native metals

Cubic, in grains and plates or disseminated H = 4 5, G = 7 to 7 8 Steel grey or iron black Fracture hackly, very magnetic B B infusible Sol in h acid Two varieties are to be distinguished (*a*) *Telluric Iron*, in grains and plates Almost pure iron or contains graphite, carbon, lead, or copper but no nickel At Chotzen in Bohemia in limestone in an argillaceous sandstone in the keuper at Muhlhausen in Thuringia along with fossils, in an ironstone conglomerate in Brazil, and in lava in Auvergne in the mine of Hackenburg at Bexley, in Liberia Africa along with quartz a zeolite, and magnetite, enclosed in magnetite in Unst (Shetland) and in Sutherlandshire in basalt in Antrim Ireland, in the gold sands of Brazil the Urals and Olahpian (Transylvania) (*b*) *Meteoric iron*, steel grey to silver white

Almost always contains nickel, with cobalt, copper, and several minerals which are non terrestrial When polished and etched with nitric acid the surface is marked by lines of unaffected interlacing crystals called Widmannstatten s figures, most of the nickel is contained in these Occurs in masses which vary in size from the smallest microscopic dust as dredged from the depths of the ocean to upwards of 32,000 ℔ Many of these masses have been seen to fall Several (suspected, however, to be terrestrial) have been found imbedded in a basaltic rock near Disco Bay in Greenland, one of which is 44,000 ℔ in weight Several contain hydrogen in their pores, condensed to the extent of eight times the volume of the mass and the pitted depressions frequently observable upon their surface give countenance to the view that, if not discharged from a volcanic throat, they were set at liberty by some sudden disrupting gaseous explosion

17 ZINC Zn

Rhombohedral Said to be found in large hexagonal pyramids Cl basal, perfect H = 2, G = 7 Lustre metallic Colour and streak bluish white Found in a geode in basalt near Melbourne, Australia coated with smithsonite, erythrine, and aragonite Also in the gold sands of the Mittamitta river

18 COPPER Cu

Cubic (figs 28 30 26, 33, 37, 264) Twins, on an octahedral face Crystals generally distorted Often filiform and arborescent, or in plates and laminæ H = 2 5 to 3, G = 8 5 to 8 9 Lustre dull metallic Colour and streak copper red with yellow or brown tarnish B B easily fusible colouring the outer flame green Sol in n acid Occurs in many rocks (generally igneous) and frequently associated with zeolites In the Faroes, Unst (Shetland) Cornwall Chessy near Lyons, the Banat (Hungary), Siberia, China, Mexico, Brazil, Chili, and Australia Masses of great size are found, much the largest being from the Ontanagon river, on the south of Lake Superior One mass found in February 1857 was 45 feet in length, 22 feet in width, and 8 feet in thickness its weight was 420 tons Another was found in 1869, 65 feet in length, 32 in width, and from 4 to 7 feet in thickness, this weighed upwards of 1000 tons, and had a value of 400,000 dollars

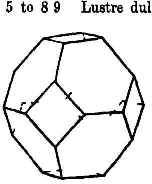


Fig 264

19 LEAD, Pb

Cubic, but only in thin plates capillary or filiform Cl none H = 1 5 G — 11 36 to 11 4 Ductile, malleable, and sectile Bluish grey, but with a blackish tarnish Found in lava in Madeira, and at the mines near Cartagena in Spain, in amygdaloid near Weissig in basaltic tufa at Rautenberg in Moravia, with gold near Mount Alatau in the Altai, at Velika in Slavonia, and at Olahpian in Transylvania near Ekaterinburg in the Urals, in the district of Zomelahuacan in Vera Cruz, in foliated galena in granular limestone, in the iron and manganese bed of Paisberg in Wermland (Sweden) with hæmatite, magnetite, and hausmannite, in white quartz north west near the Dog Lake of the Kaministiquia, an affluent of Lake Superior imbedded in hornstone in plates and grains, in the mine of Bogoslovskoi in the Kirghiz steppes in greenstone porphyry at Stutzerbach in Thuringia with hæmatite in the islands of Nias on the west coast of Sumatra

20 MERCURY, Hg

Cubic Occurs in small liquid globules in its gangue but may be solidified at – 39°, when it forms octahedral crystals G = 13 596 when liquid, 15 612 when solid Lustre brilliant metallic tin white B B volatile sometimes leaving a little silver Readily sol in n acid Occurs generally in clay shales or schists of different ages The globules of mercury are usually found in rents in cinnabar, or accompanying calomel, at most of the localities for these minerals Found at Idria in Carniola and Almaden in Spain At Idria it is obtained by washing a soft clay slate In Transylvania and Galicia springs issuing from the Carpathian sandstone bear along globules of mercury At the Pioneer mine in California some of the quartz geodes contain several pounds of mercury At Cividale in Lombardy it is found in an Eocene marl It has also been observed occasionally in drift, and has even been stated to have been found in a peat bog

21 SILVER, Ag

Cubic (figs 26, 30, 33 40, 37) Crystals generally small, also and most frequently filiform, arborescent and in plates or crusts These either project into cavities, coat their surfaces, or ramify in a reticulated manner throughout the mass of the rock Twins of octahedral and trapezohedral composition No cl H = 2 5 to 3, G = 10 1 to 11 1 Lustre metallic Colour and streak silver white, but generally tarnished yellow, brown, or black Malleable, ductile, and sectile, but less so than gold B B easily fusible Sol in n acid, the solution colours the skin black C c . silver, with varying proportions of gold, platinum, mercury, copper, antimony, and bismuth The auriferous from Norway contains silver 72, gold 28, from quartz reefs in Sutherland, silver 71 4, gold 28 6 The cupriferous from Courcy near Caen contains 10 per cent of copper The antimonial from Bohemia contains 1 per cent of antimony The mercurial from Kongsberg in Norway has 4 of mercury, found chiefly in veins in gneiss clay slate, and limestone Localities Alva and elsewhere in Scotland, Ballycorus in Ireland, and Cornwall in England, at Freiberg, Andreasberg, and Kongsberg, along with native copper at Lake Superior, in Mexico, in Peru, and in the United States The finest crystallized silver occurs at Lake Superior, and at Kongsberg At the last locality the crystals are an inch in diameter, and are disposed on large filiform brushes Silver occurs in large masses, three of 436, 560, 812 ℔ have been recorded from Kongsberg A block which smelted 44,000 ℔ was for some years used as a table by Duke Albert on his annual visits of inspection to the Schneeberg mine in Saxony A Mexican specimen was found of 400 ℔, the mines of Huantaya in Peru have yielded masses of 444 and 960 ℔ Britain produces annually about 760,000 oz of silver, chiefly, however, from lead ores The value of annual produce for the whole world from all sources is from 8 to 10 millions of pounds sterling

22 SCHNEIDERITE (*Gold Amalgam*), Au_2Hg_3.

Tetragonal four sided prisms, easily crumbling, yellowish white to white, sometimes in grains the size of a pea C c gold 41 63, mercury 58 37 Found at Mariposa in California A variety $(Au, Ag)_2 Hg_5$ is found along with platinum in Columbia, this contains gold 38 39, silver 5, mercury 57 40.

23 ARQUERITE, Ag_6Hg

Cubic In octahedra, also in grains and dendrites G = 10 8 Like native silver, but softer C c silver 86 5, mercury 13 5 From Arqueros in Coquimbo, Chili *Kongsbergite*, $Ag_{18}Hg$, occurs at Kongsberg, with 95 1 of silver and 4 9 of mercury

24 AMALGAM, $Ag\ Hg_2$, and $AgHg_3$

Cubic (fig 33, in combination with 40, 30, 41, 39) Cl dodecahedral H = 3 to 3 5 G = 10 5 to 14 Colour and streak silver white Fracture conchoidal, brittle grates when cut In closed tube yields mercury and leaves silver Sol in n acid The first variety (silver 34 8 mercury 65 2) occurs at Moschellandsberg in the Palatinate, where the veins of mercury and silver intersect one another, the second (silver 26 25, mercury 73 75) there, and also at Allemont in Dauphine, Almaden in Spain in Hungary, and in Sweden From Rosilla in Atacama (Chili) Domeyko reports the following other compounds Ag_3Hg_4, silver 46 8, mercury 53 2, white and silvery, AgHg, silver 55 1 mercury 44 9, granular and dull, Ag_5Hg_3, silver 64 2, mercury 35 8, of the last there is a mass weighing 22 ℔ in the museum of Santiago

25 GOLD, Au

Cubic (figs 30, 26, 33, 40, 36) and more complex forms Crystals generally small and indistinct through elongation, assuming capillary and arborescent shapes Also in thin plates Twins rare twin face octahedral Frequently in rounded and apparently colloidal masses impacted in clay, or loose in small grains (pipettes) rolling in the bed of streams Fig 265 is of such a mass found in Sutherland No cl H = 2 5 to 3, G = 17 to 19 4 Lustre metallic but frequently dull and partly coated with a brown crust Colour and streak yellowish white to bright gold yellow Malleable, ductile, and sectile, the purer varieties the more so and the softer B B easily fusible Sol in aqua regia, generally with precipitation of chloride of silver Solution yellow, stains skin purple red, with corrosion C c gold, with silver from 72 to 26 per cent, sometimes iron and copper under 1 per cent Found in beds and veins generally of quartz in metamorphic rocks of a schistose nature, rarely in diorite and porphyry, and very rarely in granite Its general associate is limonite, formed from decomposition of pyrite, sometimes also hæmatite and magnetite Occurs also in microscopic grains in quartz, from which it is extracted by crushing and amalgamation The geologic range is from the Azoic to the Tertiary and Cretaceous, as in California, but even in these more recent rocks the original source must have been at least Palæozoic Of localities which yield gold the following may be noticed —the Leadhills in Scotland, Wicklow in Ireland, Dolgelly in North Wales, Cornwall in England, Transylvania, Hungary, and Piedmont, the Urals, Ekaterinburg, and India, Kordofan, the coast opposite Madagascar, and the Gold Coast (the fame of which has been recently revived), Minas Geraes in Brazil, Bolivia. North Carolina, and

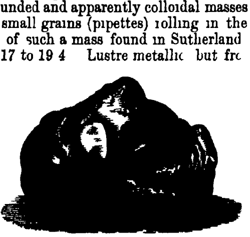


Fig 265

California, and more recently New South Wales and Queensland in Australia, Tasmania, and New Zealand

Some of the largest single masses of gold found in recent times are the following —one of 22 oz in Transylvania, of 28 ℔ in North Carolina, of 20 ℔ in California, one of 96 ℔ troy near Miask in the Urals, and one of 184 ℔ 8 oz, which yielded £8376, 10s 6d, at Ballarat, Australia

The annual produce of gold from Australia is about 5 millions of pounds sterling, of the United States about 15 millions, and the whole earth about 23 millions

The following sub species may be noticed —

1 *Electrum* This name for the alloys of gold and silver was applied by Pliny, whenever the proportion of the latter metal was one fifth An alloy of 2 gold and 1 silver contains 21 per cent of silver this is found in Sutherland One of 1 to 1 contains 36 per cent of silver, this last being the most usual proportion It occurs in Transylvania, in the Altai, and in Colombia Its colour is brass yellow to yellowish white G = 12 5 to 15 5

2 *Porpezite*, or *Palladium Gold* (*ouro poudre*), from Porpez in Brazil, contains 9 85 per cent of palladium and 4 17 of silver

3 *Rhodium Gold*, from Mexico (G = 15 5 to 16 8), contains from 34 to 43 per cent of rhodium

26 **Platinum** Pt

Cubic, rarely in small cubes or octahedrons, usually in minute scaly grains sometimes cohering, and also in rounded lumps No cl H = 4 to 4 5, G = 17 to 19 Lustre metallic Colour and streak pale steel grey Malleable and ductile with difficulty, having a hackly fracture When containing much iron, magnetipolar B B infusible Sol in aqua regia, but only when heated, solution red, corrodes the skin C c platinum, but never to a greater extent than 86 5 per cent The remainder consists of iron, iridium rhodium, palladium, osmium, gold, copper, and a mechanical mixture of irid osmine The iron exists in quantities varying from 4 3 per cent to double that amount Occurs in Brazil in syenite, near Popayan (Colombia) in alluvium, associated with chromite, iridium palladium, gold, and copper, in the Urals in alluvium derived from crystalline rocks, and at Nijni Tagilsk in serpentine along with chromite It is also found in Borneo, California, and Carolina and is said to have been found in the county of Wicklow in Ireland The sands of many rivers yield it in small amount Platinum does not occur in large masses A mass in the Madrid Museum from Condoto weighs 26½ oz, masses have been found in the Urals from 11 to 21 ℔

Iron Platina is a sub species This, which has a composition $FePt_2$, and contains from 11 to 13 per cent of iron, is found at Nijni Tagilsk G = 14 6 to 15 8 H = 6 It is magnetipolar and attracts iron much more strongly than an ordinary magnet

27 **Platiniridium**

In minute silver white grains H = 6 to 7, G = 16 94 to 22 8 Contains 55 44 platinum, 27 79 iridium, 6 86 rhodium, 4 14 iron, 3 3 copper, 49 palladium Is found in Brazil

28 **Iridium**, Ir

Cubic (fig 27) H = 6 to 7, G = 21 57 to 23 46 Cl cubic, traces Very slightly malleable Silver white to steel grey B B unchanged Insoluble in all acids C c 76 8 iridium 19 64 platinum, 0 89 palladium, 1 78 copper Found at Nijni T[illegible] generally in minute grains Is the heaviest known substance

Avaite, sub species From Ava in India C c 60 iridium, 20 platinum (according to Prinsep)

29 **Palladium**, Pd

Cubic, in minute octahedrons, and in grains H = 4 5 to 5, G = 11 3 to 11 8 Malleable Light steel grey B B infusible Slowly dissolves in n acid, forming a brown red solution C c palladium, with a little platinum and iridium From the gold sands of Brazil, often in small plumose crystalline lumps Also from St Domingo, and the Urals Does not tarnish with sulphurous fumes

30 **Allopalladium**, Pd_2

Hexagonal, in small flat hexagons Cl basal, perfect Lustre bright silvery Colour pale steel grey From Tilkerode in the Harz, with gold

31 **Newjanskite** (*Osmiridium*), IrOs (iridium 49 78, osmium 50 22) and Ir_3Os

Hexagonal, P 124° 0P, P, ∞P Generally in flat scales Cl basal perfect H = 7, G = 18 8 to 19 47 Lustre metallic Colour tin white B B unchanged Insoluble in all acids The analyses of this mineral give quantities of iridium varying from 44 to 77 per cent, and of osmium from 21 to 49 Ruthenium, rhodium, and platinum make up the 100 parts The largest quantity of ruthenium is 8 49, and one variety from New Granada was found to contain no ruthenium, but 12 3 of rhodium, which is more than double its usual amount Occurs with platinum in Choco (Colombia), at Newjansk and several localities in the Urals, in Australia, in northern California (somewhat abundantly in gold sands), also in Canada

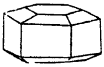


Fig 266

32 **Sisserskite** (*Iridosmium*) $IrOs_4$ (iridium 19 9, osmium 80 1) and $IrOs_3$ (iridium 24 8, osmium 75 2)

Rhombohedral, R = 84° 28 H = 7 5, G = 21 12 Colour lead grey to bluish B B becomes black, with strong odour of osmic acid, in flame of spirit lamp shines strongly, and colours flame yellowish red Occurs in small quantity with newjanskite at all its localities, and in proportionally larger quantity at Sissersk in the Urals It is used for pointing gold pens, and in the United States sells at 50 dollars an ounce

COMPOUNDS OF FLUORINE CHLORINE BROMINE, AND IODINE (HALOID SALTS)

33 **Fluorite** (*Fluor spar*), CaF

Cubic (figs 267 to 270, also figs 31, 33, 36, 55, 56 57 58) also divergent crystalline, granular, and compact Cl octahedral fracture conchoidal, brittle H = 4, G = 3 1 to 3 2 Transparent to pellucid Lustre vitreous Colourless, but generally coloured purple, blue, green, yellow, white, black and pink Sometimes two or three colours disposed in layers in one crystal Frequently phosphoresces with different tints of light, when heated B B decrepitates and fuses to an opaque bead Sol in s acid with evolution of hydrofluoric acid C c 51 3 calcium, 48 7 fluorine Common in veins, generally associated with metallic ores Shetland, Sutherland, on the Avon, and Ballater in Scotland Cumberland, Northumberland, Derbyshire and Cornwall Saxony, Bohemia, Freiberg Used to be turned into vases and other ornaments ("Blue John"), formerly employed as a flux, now for etching and obscuring glass

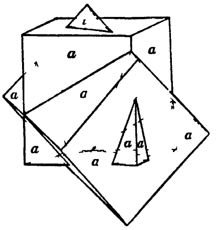


Fig 267.

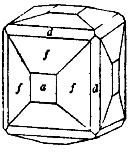


Fig 268

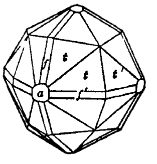


Fig 269

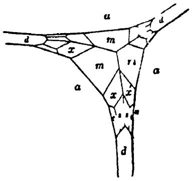


Fig 270

34 **Yttrocerite**

In crystalline crusts H = 4 to 5, G = 3 4 to 3 5 Translucent, vitreous Violet blue to grey or white B B infusible Evolves fluorine when heated with sulphuric acid C c fluorides of cerium, yttrium and calcium Fimbo and Broddbo near Falun (Sweden), Massachusetts and New York

35 **Fluocerite**, $CeF + Ce_2F_3$

Hexagonal H = 4 to 5, G = 4 7 Opaque or translucent on the [illegible]

and Broddbo

36 **Fluocerine**, $Ce_2F_3 + (Ce_2O_3 + H_2O)$

Massive fracture conchoidal H = 4 5 to 5 Opaque resinous Bright yellow to reddish brown, streak brownish yellow B B infusible, darkens with the heat, colour restored on cooling C c cerium 17 6, fluorine 10 9, sesquioxide of cerium 66 4 water 5 1 From Finbo

37 **Bastnaesite**, $Ce_2F_3 + Ce_2O_3 + 4H_2O$, and

38 **Hamartite**, $2(LaO, CeO)3CO_2 + CeF_3$ are similar The first is from Bastnaes in Sweden, the second from Pike's Peak in Colorado

39 Fluellite AlF_3

Right prismatic In acute rhombic octahedrons with truncated apex Polar edges 109 6 and 82° 12, middle 144° H = 3 Lustre vitreous Colour white transparent Stenna gwyn in Cornwall

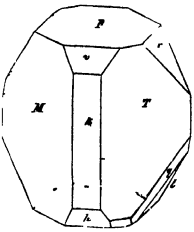


Fig 271

40 Cryolite $3NaF + Al_2F_3$

Anorthic but mostly in cleavable masses M T 91° 57 P T 90 2 T M 90° 40 Cl P perfect M and T imperfect, brittle H = 2 5 G = 2 9 to 3 08 Vitreous somewhat pearly on P Translucent after immersion in water transparent Colourless and snow white but when deep seated brown to black Melts even in flame of candle to a white enamel In open tube traces of hydrofluoric acid Sol in s acid C c aluminium 13 sodium 32 8, fluorine 54 2 Arksutfiord Greenland Miask, Siberia Used for manufacture of a white glass, and extraction of aluminium

41 Arksutite $(CaNa)_2F + Al_2F_3$ Ca Na = 1 3

Massive granular H = 2 5 G = 3 03 to 3 18 Cl one distinct Vitreous white translucent C c aluminium 18 6, sodium 23 3, calcium 6 8 fluorine 51 3 Arksutfiord

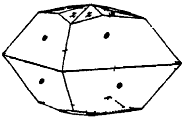


Fig 272 (species 42)

42 Chiolite $3NaF + 2Al_2F_3$

Pyramidal and twins (fig 272) Middle edge 111° 14 Mostly granular Cl imperfect H = 4 G = 2 84 to 2 9 Resinous white Fuses more easily than cryolite evolves hydrofluoric acid C c aluminium 18 6 sodium 23 4 fluorine 58 Ilmen Mts near Miask

43 Chodneffite, $2NaF + Al_2F_3$

G = 3 Other characters like chiolite, and from same locality

44 Pachnolite, $3(CaNa)F + Al_2F_3 + 2H_2O$ Ca Na = 3 2

Oblique prismatic ∞P 98° 34 always twins Vitreous white, semitransparent C c aluminium 12 3 calcium 16 1, sodium 12 4, fluorine 51 1 water 8 1 Evolves water with crackling, when heated other characters like cryolite, along with which it occurs in Greenland

45 Thomsenolite, $2(CaNa)F + Al_2F_3 + 2H_2O$ Ca Na = 7 3

Oblique prismatic Prismatic planes striated, ∞P 89° (fig 273) Cl basal perfect H = 2 5 to 4 G = 2 74 to 2 76 Vitreous cleavage face pearly White with yellow crust translucent C c aluminium 15, calcium 15 4 sodium 7 6 fluorine 52 2, water 9 8 B B fuses more easily than cryolite to clear glass decrepitating violently Along with cryolite in Greenland

46 Gearksutite $Ca_2F + Al_2F_3 + 4H_2O$

Earthy H = 2 White dull opaque C c aluminium 15 calcium 19 3 sodium 2 5, fluorine 41 2 water 20 5 Along with cryolite

47 Evigtokite $2CaF + Al_2F_6 + 2H_2O$

Crystalline Soft brittle like kaolin C c calcium 22 39 aluminium 16 23 sodium 43, fluorine 55 24 water 5 71 Arksutfiord, Greenland

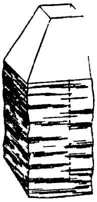


Fig 273 (sp 45)

48 Prosopite

Oblique prismatic A hydrated silico fluoride of aluminium and calcium H = 4 G = 2 89 Colourless and milled crystals From the tin mines of Altenberg

49 Calomel Hg_2Cl

Pyramidal 1 1 5 50 (fig 274) H = 1 to 2, G = 6 4 to 6 5 Translucent, adamantine Yellowish white to grey Sublimes unchanged in closed tube with soda yields mercury Insol in n acid C c mercury 85 chlorine 15 Moschellandsberg Idria, Almaden

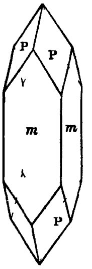


Fig 274 (sp 49)

50 Sylvite KCl

Cubic (figs 26 30) also massive Cl cubic H = 2, G = 1 9 to 2 White or colourless Vitreous soluble taste like common salt C c potassium 52 5, chlorine 47 5 B B fuses and colours flame violet Crater of Vesuvius and salt beds of Stassfurt

51 Halite (*Common Salt, Rock salt*) NaCl

Cubic (fig 21), generally granular, sometimes fibrous Cl cubic H = 2, G = 2 1 to 2 2 Transparent to translucent, vitreous Colourless or white, but often coloured red yellow, or blue. Taste saline B B fuses and partly evaporates, colours flame yellow C c sodium 39 3, chlorine 60 7 In great beds at Wieliczka, Salzburg, Bex, &c, on the Continent, Cheshire in England As an efflorescence in Brazil, Abyssinia, the Caspian and Aral Seas As a sublimation among lavas at Vesuvius and other volcanoes

52 Salmiac, NH_4Cl

Cubic (figs 30, 40, and 41 with 26, 33, 40) Cl octahedral, also stalactitic, globular, and as an efflorescence H = 1 5 to 2, G = 1 5 to 1 6 Pellucid, vitreous Colourless, but sometimes stained Taste pungent B B directly volatile, in copper colours flame blue green C c 32 ammonia, 66 4 chlorine A sublimate on active volcanoes Vesuvius, island of Volcano, Iceland Near coal seams which have taken fire, in Scotland and at Newcastle

53 Chloro Calcite, $CaCl + (KCl, NaCl)$

Cubic Vesuvian bombs

54 Cerargyrite, AgCl

Cubic (fig 26) Twins on octahedral face No cl, chiefly massive in crusts H = 1 to 1 5, G = 5 5 to 5 6 Fracture conchoidal Malleable Translucent, adamantine to resinous Grey, yellowish, and greenish B B fuses easily to a dark bead, reduced in inner flame Soluble in ammonia C c silver 75, chlorine 25 Johann Georgenstadt, Mexico, Peru

55 Embolite, $2AgBr + 3AgCl$

Cubic (fig 29), also massive or concretionary H = 1 to 1 5; G = 5 8 Adamantine to resinous Green and yellowish green. C c silver 67, chlorine 13, bromine 20 Chili, Mexico, Honduras

56 Bromite, AgBr

Cubic (figs 26, 30) H = 1 to 2, G = 5 8 to 6 Splendent Yellow to olive green, streak siskin green B B fusible easily C c silver 57 5, bromine 42 5 San Onofre and Plateros (Mexico)

57 Iodite, AgI

Hexagonal Cl basal, also massive, and in crystalline plates some inches in width, these are flexible H = 1 to 1 5, G = 5 5 to 5 7 Translucent adamantine Citron and sulphur yellow, streak yellow B B fusible, colours the flame purple red, and leaves button of silver C c silver 46 iodine 54 Zacatecas in Mexico, Algodones Chili, Arizona, rarely in Spain

58 Coccinite, HgI_2

In grains of an adamantine lustre from Casas Viejas in Mexico Colour red to yellow, in acute rhombic prisms Also from Zimapan and Culebras

59 Tocornaclite, $AgI + Hg_2I$

Amorphous, yellow, soft Chanarcillo in Chili

60 Cotunnite, PbCl

Right prismatic H = 2, G = 5 238 Transparent, high adamantine to pearly White C c lead 74, chlorine 26 Crater of Vesuvius

61 Molysite, Fe_2Cl_3

Incrusting Brownish red and yellow On lavas of Vesuvius. C c iron 34 5, chlorine 65 5

62 Carnallite, $KCl + 2MgCl + 12H_2O$

Right prismatic No cl Conchoidal fracture H = 2 to 2 5, G = 1 6 Colourless, generally red from iron C c 34 2 chloride of magnesium, 26 9 chloride of potassium, 38 9 water Stassfurt, Galicia, Persia

63 Tachhydrite, $CaCl + 2MgCl + 12H_2O$

Massive Yellow, translucent, very deliquescent In anhydrite. C c calcium 7 46, magnesium 9 51, chlorine 40 34, water 42 69. Stassfurt

64 Kremersite, $KCl + NH_4Cl + Fe_2Cl_3 + 3H_2O$

Cubic, in octahedra Ruby red Soluble Fumaroles of Vesuvius

65 Erythrosiderite, $2KCl + Fe_2Cl_3 + 2H_2O$

Right prismatic Vesuvian lava

66 Matlockite, $PbCl + PbO$

Pyramidal, P 136° 17 Crystals tabular Cl basal, fracture conchoidal H = 2 5, G = 7 21 Translucent, adamantine Yellowish white B B fuses easily with decrepitation, colours flame blue C c chloride of lead 55 5, oxide of lead 44 5 Cromford in Derbyshire

67 Mendipite, $PbCl + 2PbO$

Right prismatic, chiefly massive Cl ∞P perfect 102° 36 H = 2 5 to 3, G = 7 to 7 1 Fracture conchoidal Translucent, adamantine to pearly Yellowish or greyish white BB decrepitates, fuses easily Sol in n acid. C c · chloride of lead 40, protoxide of lead 60 Mendip Hills, and Brilon in Westphalia

68 Schwartzembergite, $PbI+2PbO$.

Rhombohedral, in thin crusts H = 2 to 2 5, G = 5 7 to 6 3 Adamantine Honey yellow. Desert of Atacama

69 Atacamite, $CuCl+3CuO,H_2O$

Right prismatic, ∞P (*M*) 112° 25, $\breve{P}\infty$ (*P*) 106° 10, $\infty\breve{P}\infty$ (*h*) (fig 275) also reniform Cl. h perfect. Semitransparent, vitreous Emerald green, streak apple green B B fuses leaving copper Easily soluble in acids C c copper protoxide 55 85, copper 14 86, chlorine 16 61, water 12 68 Atacama, Chili, Tarapaca Peru, Bolivia, Burra Burra, Australia, Serra de Bembe, Ambriz Africa, Vesuvius and (?) Etna

70 Tallingite, $CuCl, H_2O+4CuO, H_2O$

In crusts H = 3 G = 3 5 Bright blue to greenish blue Translucent, brittle Botallack in Cornwall

71 Percylite, $(PbCl+PbO)+(CuCl+CuO)$

Cubic (comb of figs 26, 30, 33, 36) H = 2 Vitreous Sky blue Sonora in Mexico

72 Connellite

Hexagonal (fig 276) *b* *r* 143° 10′ *r* *r* 132° 50 Crystals acicular Vitreous, translucent Vitriol blue A chloride and sulphide of copper Wheal Unity and Wheal Damsel (Cornwall)

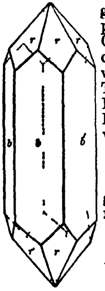


Fig 275 (sp 69)

Fig 276 (sp 72)

OXIDES OF METALS.

1 Suboxides and Protoxides

73 Cuprite, Cu_2O.

Cubic (figs 22, 30, 33, 26, with 39, 40) Compact and granular Cl octahedral, brittle H = 3 5 to 4, G = 5 7 to 6 Transparent and opaque, adamantine When transparent, crimson, when opaque, cochineal or brick red Often tarnished grey B B becomes black, fuses, and is reduced on charcoal Soluble in acids and in ammonia C c 88 9 copper, 11 1 oxygen Cornwall, Siberia, Banat, Chessy near Lyons Linares in Spain Urals, South Africa, Burra Burra Valuable copper ore *Chalcotrichite* consists of cubes elongated so as to become fibrous Tile ore is a ferruginous variety Hepatic copper, liver ore, or pitchy copper ore seems to be a product of the decomposition of chalcopyrite *Delafossite*, $Cu_2O+Fe_2O_3$, from Bohemia and Siberia

74 Water, H_2O

Hexagonal, when solid, in complex twins in snow crystals rhombohedric by cleavage, in ice H = 1 5, G = 918 Hence 1000 of water = 1089 5 of ice, or water expands $\frac{1}{11}$th in freezing Transparent, vitreous Colourless, but in bulk pale emerald green R 117° 23 Cl basal Water when pure colourless, in mass bluish green Occurs in centre of geodes of chalcedony in China, of druses of quartz in California and many other countries, in zeolitic cavities to the amount of several gallons in the Faroes, also in the Hebrides, &c Water of the ocean, from holding saline matters in solution, has G = 1 027 to 1 0285 Waters of saline lakes contain sometimes 26 per cent of salts, and have G 1 212 Besides its vast bulk in the ocean water occurs in enormous amount in the solid form, often as water of crystallization in rocks and minerals *e g*, zeolites Igneous rocks in some districts are converted largely into saponite, which contains 25 per cent of water Water is the standard for specific gravities of solids and liquids, 1 cubic inch at 60° F and 30 inches of the barometer weighs 252 458 grains 1 litre weighs 1000 grammes.

75 Periclase, MgO.

Cubic, in cubes and octahedrons Cl do H = 6 G = 3 6 to 3 75 Transparent, vitreous Grey to dark green B B infusible Sol in acids C c magnesia, with 6 to 8 of iron oxide. Somma

76 Bunsenite, NiO

Cubic, in octahedrons H = 5 5. G = 6 4 Vitreous Pistachio green. Johann Georgenstadt

77. Zincite, ZnO

Hexagonal and granular Cl basal H = 4 to 4 5, G = 5 4 to 5 5 Adamantine, translucent Blood or hyacinth red, streak orange yellow. B B infusible, but phosphoresces C c zinc 80 26 oxygen 19 74 sometimes with manganese peroxide Valuable ore of zinc Franklin and Sterling in New Jersey

78 Massicot, PbO

Massive, scaly crystalline. H = 2, G = 7 8 to 8 Sulphur or lemon yellow, often contains iron Popocatepetl in Mexico.

79 Melaconite, CuO

Cubic compact H = 3 to 4, G = 6 to 6 3 Black B B infusible soluble in acids. Cornwall, Leadhills, Lake Superior, Burra Burra

80 Tenorite, CuO

Oblique prismatic, occurs in thin scales of metallic lustre on lava of Vesuvius Colour black and dark red.

2 Sesquioxides.

81 Corundum, Al_2O_3

Hexagonal, R 86° 4 Twins common Cl. rhombohedral, and basal Excessively tough, and difficultly frangible H = 9, G = 3 9 to 4 2 Transparent or translucent, vitreous, but pearly to metallic on basal face B B unchanged As *Corundum*, white, grey, and greenish frequently with bronzy lustre on basal face C c alumina, with a little peroxide of iron China, Ceylon, Bohemia, Malabar, Macon in North Carolina (one crystal 300 ℔ weight) *Emery* is compact crystalline granular grey to indigo blue Asia Minor, Naxos, Spain, Greenland America Corundum is used when crushed for cutting and polishing gems in China and India, emery in powder for grinding Alumina occurs also in a purer state in transparent crystals of various tints of colour When red and of the colour of pigeon's blood they are termed *Rubies*, these come from Syriam in Pegu Ava Ceylon, Bohemia, and near Expailly When 5 carats in weight a ruby is twice the value of a diamond of the same size when 10 carats three times the value When blue the crystal is the *Sapphire*, found chiefly in Ceylon and Pegu when green it is the *Oriental Emerald*, when yellow the *Oriental Topaz*, when purple the *Oriental Amethyst*,—the adjective here distinguishing them from the true or occidental stones of the same name Other tints of colour also occur, but with the exception of the red and blue they are seldom pure or deep The prism when cut with a hemispherical dome sometimes displays a six rayed star either of a bright gold or a silvery white colour upon a greyish blue ground These receive the name of *Asteria Sapphires* The same crystal frequently shows portions of even three different tints When perfectly devoid of colour, they are called *Water Sapphires* such are little inferior to the diamond in brilliancy, but do not disperse rays of light to the same extent

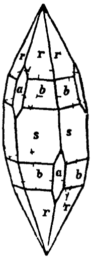


Fig 277

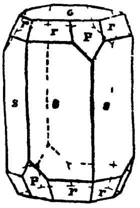


Fig 278

82 Hæmatite, Fe_2O_3

Hexagonal and rhombohedral R 86° Crystals rhombohedric, prismatic, and tabular Twins with axes parallel Cl R and basal, fracture conchoidal, brittle H = 5 5 to 6 5 G = 5 1 to 5 3 Opaque but in thin laminæ transparent and blood red Brilliant metallic lustre iron black to steel grey, often brilliantly tarnished of red, yellow, green, and blue tints, streak cherry red B B in the inner flame becomes black and magnetic Sol in acids C c iron 70, oxygen 30 The following are varieties or subdivisions —

Elba Iron Ore, highly modified rhombohedral crystals, often brilliantly tarnished *Specular Iron Ore*, in thin flat crystals often from volcanoes as on the island of Ascension, this variety includes *Micaceous Iron* thin lamellar, and curved and *Red Iron Froth* scaly *Red Hæmatite*, in botryoidal and stalactitic forms, which are internally composed of radiating fibres, and often have a concentric structure, the external surface has a dark red to a brownish red hue *Compact* and *Ochrey* varieties with more or less aluminous impurity, pass into *Reddle* or red chalk, and when still more earthy into jaspery and columnar ores This ore is very commonly distributed —micaceous iron at Pitfichie in Aberdeen and Birnam in Perthshire red hæmatite at Leadhills and at

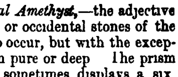


Fig. 279.

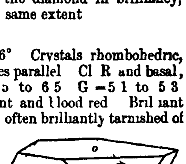


Fig 280

Ulverston in Lancashire, specular iron at Tavistock in Devonshire and in Cumberland *Martite* seems to be the same substance in pseudomorphs after magnetite it occurs in octahedra in Bute, Framont (Vosges), New York, and Brazil

83 Ilmenite $(Fe,Ti)_2O_3$

Rhombohedral, R 86° Crystals rhombohedral and tabular, also in twins Cl basal fracture conchoidal H = 5 to 6, G = 4 66 to 5 Opaque semimetallic, iron black to dark brown, streak black or reddish brown Sometimes slightly magnetic B B infusible, but with microcosmic salt forms a red glass Slowly sol in s acid when powdered C c peroxide of iron, with from 8 to 53 per cent oxide of titanium Occurs in metamorphic rocks Common in chloritic gneiss in Scotland, Menaccan (Cornwall), Ilmen Mountains, Salzburg, Egersund (Norway), Arendal, Dauphine (*Crichtonite*), Massachusetts (*Washingtonite*)

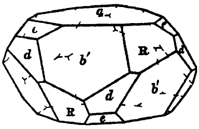


Fig 281

84 Iserine

Cubic, in octahedra Strongly magnetic, in other respects similar to ilmenite, but occurs in igneous rocks Common as black iron sand in Scotland, Iserweise in Bohemia, Auvergne, Canada, New Zealand

3 Compounds of Sesquioxides with Protoxides (Spinels)

85 Magnetite FeO, Fe_2O_3

Cubic (figs 35, 30, 33, 29, 34, 37, with 40, 41, 36) Hemitropes common on octahedral face (fig 169) Twins (fig 261) Faces of ∞O striated in long diagonal Often compact and granular Cl octahedral, fracture conchoidal or uneven, brittle H = 5 5 to 6 5, G = 4 9 to 5 2 Opaque, lustre metallic Iron black to brown, streak black Highly magnetic, often polar, forming natural magnets B B becomes brown and non magnetic, fusing with difficulty Powder sol in h acid C c 31 protoxide and 69 peroxide of iron, or 72 4 iron, 27 6 oxygen, sometimes with titanic acid In crystals in Shetland and Sutherland, also Cornwall and Antrim, Traversella (Piedmont), Tyrol, Styria Massive at Dannemora and Taberg (Sweden), Norway, Urals, Harz, Saxony, Elba This is the most important ore in Norway, Sweden, and Russia, and affords the finest iron

86 Magnesio Ferrite, MgO, Fe_2O_3

Cubic (fig 30) H = 6 to 6 5, G = 4 57 to 4 66 Other characters same as magnetite C c magnesia 20, peroxide of iron 87 Fumaroles of Vesuvius

87 Jacobsite, $(MnO, MgO), (Fe_2O_3, Mn_2O_3)$.

Cubic, O Black, vitreous, streak red Nordmark in Sweden

88 Franklinite, $(FeO, ZnO, MnO), (Fe_2O_3, Mn_2O_3)$

Cubic (figs 34, 64), also granular Cl octahedral, fracture conchoidal, brittle H = 5 5 to 6 5, G = 5 07 Metallic lustre Iron black, streak reddish brown Opaque, slightly magnetic B B infusible, but shines and throws out sparks On charcoal with soda a deposit of oxide of zinc Sol in h acid with evolution of chlorine C c about 67 iron oxide, 17 manganese peroxide, 16 zinc oxide Franklin and Sterling (New Jersey)

89 Chromite, FeO, Cr_2O_3

Cubic, in octahedra, generally granular massive H = 5 5, G = 4 4 to 4 5 Opaque, semimetallic to resinous Iron black to dark brown, streak reddish brown Fracture uneven, sometimes magnetic B B unchanged, in red flame becomes magnetic, with borax forms an emerald green bead Not soluble in acids C c 19 to 37 protoxide of iron 0 to 15 magnesia, 36 to 64 peroxide of chromium, 9 to 21 alumina Unst (Shetland), Towanrieff (Aberdeenshire), Silesia, Bohemia, Styria, Urals, Turkey, Baltimore, Massachusetts, and Hoboken The ore of chromium, used for dyes *Irite* is chromite mixed with iridosmium

90 Uraninite (*Pitch Blende*), UO, U_2O_3

Cubic (fig 30), usually massive and botryoidal H = 5 to 6, G = 6 5 to 8 Lustre pitch like to submetallic Colour velvet black, brownish black, and grey B B infusible Not sol in h acid, but easily in hot n acid C c oxides of uranium 80, with a mixture of other oxides Johann Georgenstadt Annaberg, Przibram, Redruth in Cornwall The chief ore of uranium

91 Gahnite, ZnO, Al_2O_3

Cubic (figs 166, 30, 33, and with 39, 40) Hemitropes like magnetite Cl O, brittle, with conchoidal fracture H = 7 5 to 8, G = 4 3 to 4 9 Opaque, vitreous to resinous Dark leek green to blue, streak grey B B unchanged Unaffected by acids or alkalies C c 44 oxide of zinc, 56 alumina Falun, Broddbo, Haddam in Connecticut, and Franklin in New Jersey *Dysluite* contains 42 per cent sesquioxide of iron, and *Kreittonite* contains 24 oxide of manganese

92 Hercynite, FeO, Al_2O_3

Cubic, generally granular massive H = 7 5 to 8, G = 3·9 to 3 95 B B infusible C c oxide of iron 41 1, alumina 58 9 Ronsberg in the Bohmerwald

93 Spinel, MgO, Al_2O_3

Cubic (figs 30, 33, 40 with 26), hemitropes united by face of O Cl. octahedral, fracture conchoidal H = 8, G = 3 4 to 4 1 Transparent to opaque, vitreous Black, red, blue, green, streak white B B infusible and unchanged C c 28 magnesia, 72 alumina, some with a little iron, and the red varieties some chromium Varieties are—*Spinel Ruby* when scarlet, *Balas Ruby* when rose-red, both often sold as the true ruby, but not nearly so valuable, when of 4 carats valued at half the price of a diamond the same size These come from Pegu (native name Balachan) The violet coloured is the *Alabandine ruby* from Alabandin in Caria, (Asia Minor) The orange red is the *Rubicella* The above also occur at Ceylon, Java, and Siam

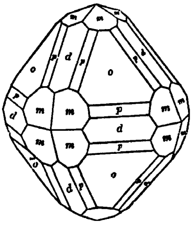


Fig 282

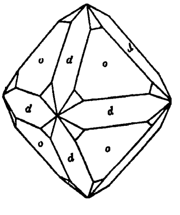


Fig 283

Sapphirine is pale sapphire blue to greenish or reddish blue, from Aker in Sweden, Greenland, and North America *Pleonaste*, dark green or blue to black, from Candy in Ceylon *Chlorospinel*, grass green with a yellowish white streak, from Zlatoust *Water spinel* colourless, from Ceylon *Picotite* is a dark blue chromiferous variety from serpentine

94 Chrysoberyl, GlO, Al_2O_3

Right prismatic (fig 284) Twins common, united by a face of P∞ (fig 285, also 156) Cl brachydiagonal imperfect, macrodiagonal more so, fracture conchoidal H = 8 5, G = 3 68 to 3 8 Transparent or translucent, vitreous Greenish white, leek green, and dark emerald green B B infusible Not affected by acids C c glucina 20, alumina 80 Brazil, Ceylon, India, the Urals, Haddam in Connecticut A very valuable gem It sometimes possesses an opalescent band, which when the stone is cut *en cabochon* appears as a streak of floating light, whence it derives its name of *Cymophane* It is then also called the chatoyant or Oriental chrysolite, and when fine is of extreme value The emerald green variety, or *Alexandrite*, is columbine-red by transmitted light

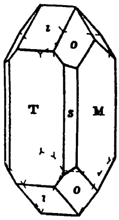


Fig 284 (sp 94)

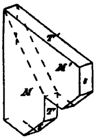


Fig 285

4 Deutoxides

95 Rutile, TiO_2

Pyramidal, prisms dominant P 84 40′, P∞ 65° 35′ (figs 286, 287) Hemitropes common, with axes of halves 114° 26′ Cl ∞ P and ∞P∞, perfect H = 6 to 6 5, G = 4 2 to 4 3 Transparent to opaque, adamantine lustre Brown red, red, pale yellow, and black, streak yellowish brown B B unchanged, with borax in the ox flame forms a greenish, in the red flame a violet glass Not affected by acids C c titanic acid, with some peroxide of iron Craig cailleach and Ben y Gloe (Perthshire), The Cobbler and Ben-Bheula (Argyllshire), Alps, Limoges, Norway, Brazil Large crystals at Titanium Mount (Lincoln county, Georgia) Used in porcelain painting, and for tinting artificial teeth When attenuated crystals are imbedded in rock crystal they are called Venus' hair

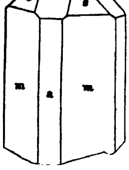


Fig 286

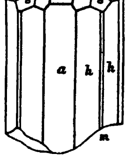


Fig 287

96 ANATASE, TiO_2.

Pyramidal, pyramids dominant P 136° 36 (fig 288) Cl basal, and P, both perfect, brittle H = 5 5 to 6, G = 3 8 to 3 93 Transparent to opaque, lustre adamantine to metallic Indigo blue, yellow, brown, rarely colourless, streak white B B infusible Sol in hot s acid C c titanic acid, with a little iron and rarely tin Cornwall and Devonshire, the Alps, Dauphiné, Valais, the Urals Minas Geraes (Brazil)

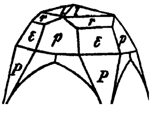


Fig 288 (sp 96)

97 BROOKITE TiO_2

Right prismatic, with polar edges 135° 37 and 101° 3 (fig 289) Cl macrodiagonal H = 5 5 to 6, G = 3 86 to 4 2 Transparent to opaque, lustre metallic adamantine Yellowish, reddish, and hair brown streak yellowish white to white B B infusible with microcosmic salt, a brownish yellow glass C c titanic acid, with 1 to 4 5 per cent peroxide of iron Snowdon and Tremadoc (Wales) Chamouni, Bourg d Oisans, Miask *Arkansite* is iron black and submetallic, in thick crystals from Arkansas, U S

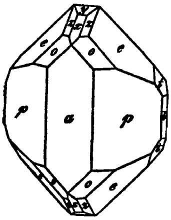


Fig 289 (sp 97)

98 CASSITERITE SnO_2

Pyramidal P 87° 7, P∞ 67° 50 (figs 290 to 292) Crystals ∞P, P, or ∞P (*g*) P (*s*) ∞P∞ (*l*), or with P∞ (*P*) (fig 290) and also ∞P2 (*r*) and 3P$\frac{3}{2}$ (*z*), (fig 291) Hemitropes very common, combined by a face of P∞ with the chief axes 112° 10 (figs 293, 171, 172, 173), also fibrous (*Wood Tin*), or in rounded fragments and grains (*Stream Tin*) Cl prismatic along ∞P, and ∞P∞, imperfect brittle H = 6 to 7, G = 6 8 to 7 Translucent or opaque, adamantine or resinous White, but usually grey, yellow, red, brown and black streak white, light grey, or brown B B in the forceps infusible on charcoal, in the inner flame, reduced to tin Not affected by acids C c 78 6 tin and 21 4 oxygen, but often mixed with peroxide of iron, or manganese, or tantalic acid Cornwall Bohemia, Saxony also Silesia, Haute Vienne in France, Greenland Russia, North and South America, Malacca, Banca, and Queensland Almost the only ore of tin

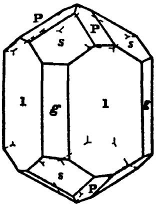


Fig 290

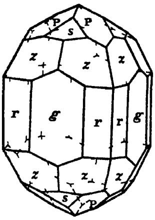


Fig 291

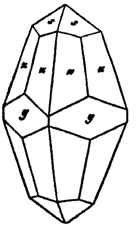


Fig 292

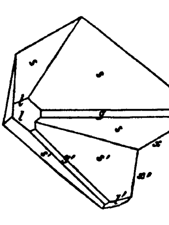


Fig 293

99 HAUSMANNITE, $2MnO, MnO_2$

Pyramidal P 116° 59, P∞ 98° 32 (fig 110) Twins common and rosettes of twins (figs 174, 175) Cl basal, perfect, less so P and P∞, fracture uneven. H = 5 5, G = 4 7 to 4 8 Opaque, metallic lustre Iron black, streak brown B B infusible, but becomes brown Sol in h acid, with evolution of chlorine Powder colours s acid red C c 31 protoxide and 69 peroxide of manganese Ihlefeld and Ilmenau in the Harz, and Sweden

100 BRAUNITE, MnO, MnO_2

Tetragonal P 108° 39 Cl P, brittle H = 6 to 6 5, G = 4 7 to 4 9 Metallic lustre Colour and streak dark brownish black C c 70 manganese and 30 oxygen generally with about 8 per cent of silica Ihlefeld and St Marcel *Marceline* has violet tarnish

101 PYROLUSITE, MnO_2

Right prismatic ∞P 93° 40, generally radiating fibrous, or compact earthy Cl ∞P friable H = 2 to 2 5, G = 4 7 to 5 Opaque, lustre silky to semi metallic Dark steel grey to black streak black Soils B B infusible, loses oxygen and becomes brown Sol in h acid, with evolution of chlorine C c manganese 63, oxygen 37 Arndilly (Banffshire), Cornwall and Devon Ilmenau, Ihlefeld, France, Hungary Brazil Used for removing the green iron tint from glass, hence its name and that of *Savon de verrier* Also for obtaining oxygen and chlorine *Varvicite* is a variety with 5 per cent of water, from Warwickshire

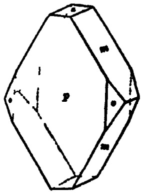


Fig 294

102 CREDNERITE $3CuO, 2(MnO, MnO_2)$

Oblique H = 4 5 G = 5 Metallic Black, streak brown. Thuringia

103 PLATINERITE, PbO_2

Hexagonal ∞P 120° Cl indistinct, brittle G = 9 4 Opaque, metallic Iron black streak brown C c lead 86 2, oxygen 13 8 Leadhills

104 MINIUM $2PbO, PbO_2$

Pulverulent H = 2 to 3, G = 4 6 Dull Colour bright red, streak orange yellow B B fuses easily and reduced. Sol in h acid C c lead 90 7, oxygen 9 3 Leadhills, Weardale in Yorkshire, Anglesea, Badenweiler, Siberia.

5 HYDROUS OXIDES.

105 SASSOLINE, B_2O_3, H_2O

Anorthic 0P $\infty\breve{P}\infty$ 75° 30 Scaly six sided plates Cl basal Flexible and sectile H = 1, G = 1 4 to 1 5 Translucent pearly white taste bitter, greasy Sol in hot water C c boracic acid 56 45 water 43 55 Hot springs of Sasso, near Siena Tuscany and with sulphur in the crater of Volcano Lipari Islands

106 TURGITE, $2Fe_2O_3+H_2O$

Massive and fibrous, also earthy H = 5 to 6, G = 3 54 to 4 68 Lustre satin like, also dull Colour reddish black to bright red. Botryoidal surfaces lustrous like limonite Opaque C c iron sesquioxide 94 7, water 5 3 B B. decrepitates violently and yields water Kerrera (Hebrides), Bogoslovsk (Urals), and many limonite localities. Frequently taken for limonite

107 DIASPORE Al_2O_3 H_2O

Right prismatic, ∞P 129° 47′, usually thin foliated Cl brachydiagonal, perfect, brittle H = 6, G = 3 3 to 3 4 Vitreous, pearly on cleavage planes Colourless to yellowish, greenish, or violet B B infusible, decrepitates Insoluble C c alumina 85, water 15 Schemnitz Broddbo, Switzerland, Naxos, Chester, -- chusetts Fig 295

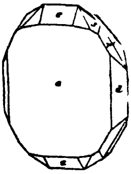


Fig 295 (sp 107)

108 GOTHITE Fe_2O_3, H_2O

Right prismatic ∞P 94° 53, also columnar fibrous, or scaly Cl brachydiagonal, perfect, brittle H = 5 to 5 5, G = 3 8 to 4 4 Opaque or fine crystals transparent and hyacinth red, lustre adamantine or silky Colour yellow, red, or dark brown streak brownish yellow B B becomes magnetic, difficultly fusible Sol in h acid C c peroxide of iron 90, water 10 Hoy (Orkney), Achavarasdale (Caithness), Salisbury Crags (Edinburgh), Lostwithiel, Clifton, Bristol, Przibram, Siegen, Saxony, Urals, North America.

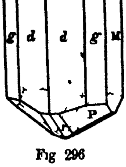


Fig 296

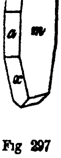


Fig 297

109 Manganite, Mn_2O_3, H_2O

Right prismatic, sometimes hemihedric, ∞P (M) 99 40 Crystals prismatic (figs 298 to 300) vertically striated, also columnar or fibrous Hemitropes common Cl brachydiagonal, perfect, brittle H = 3 5 to 4 G 4 3 to 4 4 Opaque, metallic lustre Steel grey to iron black, streak brown B B infusible Sol in warm h acid C c peroxide of manganese 89 9 water 10 1 Grandholm (Aberdeenshire) Cork, Upton Pyne (Exeter) Churchhill (Somerset) Warwickshire, Ihlefeld, Thuringia, Norway, Sweden, Nova Scotia

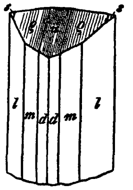


Fig 298

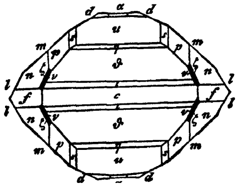


Fig 299 (sp 109)

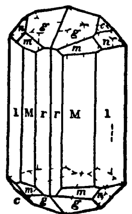


Fig 300 (sp 109)

110 Limonite, $2Fe_2O_3+3H_2O$.

Fibrous, botryoidal and stalactitic, sometimes earthy H = 4 5 to 5 5, G = 3 4 to 3 95 Opaque lustre silky, glimmering, or dull Brown, yellowish and blackish brown, often black on surface, streak ochre yellow In closed tube yields water and becomes red B B in inner flame becomes magnetic, fusing to a glass C c peroxide of iron 85 6, water 14 4 Sandlodge (Shetland), Hoy (Orkney), Clifton, Bristol, Cornwall Harz, Thuringia, Nassau, Styria, Carinthia, Siberia, United States

111 Xanthosiderite, Fe_2O_3, $2H_2O$

Fibrous, stellate, also as an ochre H = 2 5 Silky or greasy, pitch like or earthy In needles, golden yellow or brown red as an ochre, yellow, red, or brown, streak ochre yellow B B like limonite C c peroxide of iron 81 6, water 18 4 Hoy (Orkney), Achavarasdale, Kilbride, Wicklow, Ilmenau, Goslar, and Elbingerode in the Harz

112 Beauxite, $(3Al_2O_3, Fe_2O_3)$, $2H_2O$

Oolitic, concretionary, disseminated, also earthy and clay like G = 2 55 White, grey, ochre yellow, brown, and red C c alumina 50 4 peroxide of iron 26 1 water 23 5 From Beaux (or Baux) near Arles, and elsewhere in France In grains in compact limestone Pure varieties used for manufacture of aluminium

113 Eliasite, $U_2O_3+2H_2O$.

Amorphous masses, resin like H = 3 5 to 4 5, G = 4 to 5 Reddish brown to black, streak wax yellow to olive green C c 68 5 per cent sesquioxide of uranium 10 of water, with impurities Elias mine (near Joachimsthal)

114 Brucite, MgO,H_2O

Rhombohedral, R 82° 22, also foliated and botryoidal columnar Cl basal, perfect sectile, laminæ flexible H = 2 G = 2 3 to 2 4 Translucent, pearly Colourless B B infusible Easily soluble in acids C c 69 magnesia 31 water *Nemalite* is a fibrous variety with silky lustre Swinaness and Quin Gio in Unst, Beresovsk in the Urals, Hoboken, New Jersey, Texas, Pennsylvania

115 Pyrochroite, MnO, H_2O

Foliated H = 2 5 Pearly, white, but changing through bronze to black Flesh red by transmitted light In matrass becomes verdigris green, finally black, yielding water Sol in h acid C c protoxide of manganese 79 8, water 20 2 In veins in magnetite at Paisberg in Sweden

116. Gibbsite (*Hydrargillite*), Al_2O_3, $3H_2O$.

Hexagonal C c 65 5 alumina, 34 5 water The crystals are from Zlatoust in the Urals stalactites from Richmond in Massachusetts and Villa Rica in Brazil

117 Limnite, Fe_2O_3, $3H_2O$

Massive in stalactites, also as a yellow ochre Like limonite, but pitchy lustre C c peroxide of iron 74 8 water 25 2 Leadhills, Botallack (Cornwall), Novgorod (Russia)

118 Hydrotalcite, Al_2O_3, $3H_2O+6MgO$, H_2O+6H_2O.

Hexagonal Cl basal, foliated and somewhat fibrous H = 2, G = 2 04 White, pearly Greasy to the touch Translucent C.c. · alumina 16 8, magnesia 39 2, water 44 Zlatoust, Urals, Snarum Norway New York.

119 Pyroaurite, Fe_2O_3, $3H_2O+6MgO$, H_2O+6H_2O.

Hexagonal, tables and scaly coatings Lustre pearly to submetallic Colour white to gold yellow Translucent B.B infusible, yields water Sol in h acid C c peroxide of iron 23 9, magnesia 35 8, water 40 3. Haaf Grunay in Shetland, Långban in Wermland

120 Gummite, U_2O_3, $3H_2O$.

In rounded lumps, resembling gum H = 2 5 to 3; G = 3 9 to 4 2 Lustre greasy Reddish yellow to yellowish brown C c 72 per cent sesquioxide of uranium water 14 75, with impurities. Johann-Georgenstadt

121 Psilomelane, $(BaO, MnO)\ MnO_2+3H_2O$, MnO_2+3H_2O.

Massive and botryoidal, fracture conchoidal H = 5 5 to 6, G = 4 1 to 4 3 Bluish black B B infusible About 80 per cent of oxide of manganese, with baryta potash, and water Hoy (Orkney), Leadhills, Cornwall, Devon, Schneeberg, Ilmenau, Vermont in France *Wad* is similar, but sometimes soft and light. Leadhills, Cornwall, Harz, France

122 Chalcophanite, $MnOZnO+2MnO_2+2H_2O$.

Hexagonal. R R 114° 30 Cl basal H = 2 5, G = 3·91 Metallic lustre Blue black, streak brown, dull Opaque, flexible C c manganese binoxide 59 94, protoxide 6 6, zinc oxide 21 7, water 11 6 Sterling Hill (New Jersey)

OXIDES OF NON METALS

1 Oxides of Arsenic Antimony Family (Teroxides)

123 Arsenolite, AsO_3

Cubic, in octahedra, also botryoidal, stalactitic H = 1 5, G = 3 7 Lustre vitreous White, streak pale yellow Translucent Sublimes in closed tube, condensing in brilliant octahedra C c arsenic 75 76, oxygen 24 24 Cornwall, Andreasberg, Joachimsthal. Kapnik (Hungary), Nevada, California

124 Senarmontite, SbO_3

Cubic, in octahedrons Cl octahedral, also massive granular. H = 2 to 2 5, G = 5 22 to 5 3 Transparent, adamantine White or grey B B in inner flame fuses and colours the flame greenish blue Sol in h acid C c antimony 83 56, oxygen 16 44 Endellion in Cornwall, Constantine in Algeria, Malaczka in Hungary.

125 Valentineite, SbO_3

Right prismatic, ∞P137° Cl ∞P, perfect H = 2 5 to 3, G = 5 5 to 5 6 Translucent, adamantine to pearly Yellowish white, brown grey, streak white Other properties and composition like senarmontite Glendinning (Dumfriesshire), Przibram, Braunsdorf (Saxony), Harz, Hungary, Allemont (Dauphine), Siberia.

126 Bismite, BiO_3

Massive, earthy G = 4 36 Grey, yellow, green C c bismuth 89 65, oxygen 10 35 St Agnes (Cornwall), Schneeberg, Siberia.

127 Molybdite, MoO_3

Right prismatic, ∞P 136° 48′ In capillary crystals, also powdery H = 1 to 2, G = 4 5 Straw yellow to yellowish white C c molybdenum 65 71, oxygen 34 29 With molybdenite at many of its localities

128. Tungstite, WO_3.

Earthy Soft yellow or yellowish green Sol in alkalies C c tungsten 79 3, oxygen 20 7 Cumberland and Cornwall, Monroe in Connecticut

129 Cervantite, SbO_3+SbO_5.

Right prismatic Acicular, generally earthy H = 4 to 5, G = 4 1 Isabel yellow, reddish white B B on charcoal reduced, unaltered *per se* Sol in h acid Harehill, Ayrshire, Endellion, &c, Cornwall, Cervantes, Spain, Felsobanya, Hungary, Mexico, Canada, California

130 Stibiconite, SbO_4, H_2O

Massive, powdery H = 4 to 5 5 G = 5 28 Pale yellow In closed tube yields water C c antimony 74 9, oxygen 19 6, water 5 5 Goldkronach (Bavaria)

131 Volgerite, SbO_5, $5H_2O$

Massive and powdery White In tube yields water, below redness C c antimony 58 9, oxygen 19 3, water 21 8 Constantine in Algeria

132 Zundererz (*Tinder Ore*)

In soft, flexible, tinder like masses Colour dark cherry red to blackish red, lustre glimmering Two varieties —one, from Klausthal, contains antimony oxide 33, iron oxide 40, lead 16, sulphur 4, the other, from Andreasberg and Klausthal, seems to be a mixture of jamesonite (82 04 per cent), mispickel (13 46), and pyrargyrite (4 34)

133 Tellurite.

Yellowish or whitish Radiated, spherical masses. Gives the reactions of tellurous acid Facsebaya and Zalathna, Colorado.

134 TANTALIC OCHRE

Powdery, brown, vitreous Pennikoja in Finland

2 OXIDES OF CARBON SILICON FAMILY (BINOXIDES)

135 QUARTZ, SiO$_2$

Hexagonal, the purest varieties tetartohedral The primary pyramid P has the middle edge = 103° 34, and the polar edges = 133° 44, and is often perfect Very frequently it appears as a rhombohedron R (or ½P), with polar edges = 94° 15 Crystals often of ∞P, P or ∞P, P, 4P, the forms ∞P and 4P being combined in an oscillatory manner producing striæ on the face of the prism (figs 303, 304, 305), also ∞P, P, ¼(2P2), the last face appearing as a rhomb replacing the alternate angles between the two other forms (figs 307, 308) They are prismatic, or pyramidal, or rhombohedral, when P is divided into R and − R the latter very often wanting Many faces plagihedral, as in figs 302, 306,

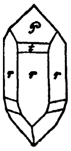


Fig 301

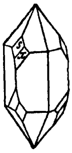


Fig 302

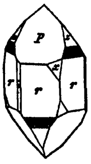


Fig 303

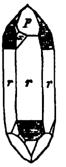


Fig 304

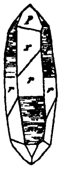


Fig 305

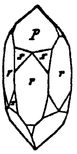


Fig 306

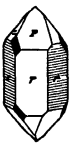


Fig 307

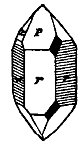


Fig 308

Twins common with parallel axes, and either merely in juxtaposition (see fig 178) or interpenetrating Crystals often distorted, as in figs 310 to 313 The crystals occur either single, attached, or imbedded, or in groups and druses Most frequently granular, massive, fibrous, or columnar, also in pseudomorphs petrifactions, and other forms Cl rhombohedral along R, very imperfect, prismatic along ∞P, still more imperfect, fracture conchoidal uneven, or splintery H = 7, G = 2 5 to 2 8, 2 65 in the purest varieties Colourless, but more often white, grey, yellow, brown, red, blue green, or even black Lustre vitreous inclining to resinous transparent or translucent, when impure almost opaque B B infusible alone with soda effervesces, and melts into a clear glass Insoluble in acids, except the hydrofluoric, when pulverized, slightly soluble in solution of potash C c 48 05 silicon and 51 95 oxygen but frequently a small amount of the oxides of iron or titanium, of lime alumina, and other substances

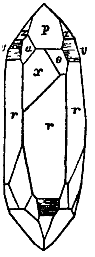


Fig 309

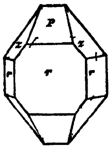


Fig 310.

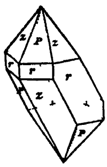


Fig 311

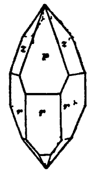


Fig 312

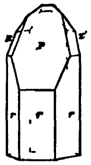


Fig 313

The following are varieties —

Rock crystal highly transparent and colourless, Dauphine, Switzerland Tyrol, Hungary, Madagascar, and Ceylon

Amethyst violet blue (from iron peroxide or manganese), and often marked by zigzag or undulating lines, and the colour disposed in clouds, Siberia, Persia, India, Ceylon, Brazil (white or yellow, named false topaz), Hungary, Ireland (near Cork), and Aberdeenshire Wine yellow (*Citrin* and *Gold Topaz*), the brown or *Smoky Quartz* (coloured by a substance containing carbon and nitrogen), and the black or *Morion*, from Siberia, Bohemia, Pennsylvania, and other places *Cairngorm Stone*, black, brown or yellow, from Aberdeenshire mountains The above are valued as ornamental stones, those which follow are less so

Rose Quartz red inclining to violet blue Clashnaree Hill (Aberdeen), and Rabenstein in Bavaria *Milk Quartz* milk white, and slightly opalescent, Greenland *Prase* leek and other shades of green, Saxony and Cedar Mountain in South Africa *Cat's eye*, inclosing asbestos greenish white or grey, olive green, red, brown, or yellow, Ceylon and Malabar *Avanturine*, enclosing mica yellow, red, green or brown, India, Spain, and Scotland *Siderite* indigo or Berlin blue, Golling in Salzburg

Common Quartz, crystallized or massive, white or grey, also red, brown, &c, is a frequent constituent in many rocks Some impure varieties are properly rocks, as —

(1) *Ferruginous Quartz*, or *Iron Flint* red, yellow, or brown, often associated with iron ores

(2) *Jasper* red, yellow, brown, also green, grey, white, and black, alone, or in spots, veins, and bands (*Ribbon* or *Egyptian Jasper*) Urals Tuscan Apennines, Harz and many parts of Scotland

(3) *Lydian Stone*, or *Flinty Slate* black, grey, or white, has a splintery or conchoidal fracture, breaks into irregular fragments, and passes by many transitions into clay slate, of which it is often merely an altered portion, as in Scotland, used as a touchstone for gold, and at Elfdal (Sweden) manufactured into ornaments

(4) *Hornstone* or *Chert* compact, conchoidal, splintery fracture, translucent on the edges, dirty grey, red yellow, green, or brown, passes into flinty slate or common quartz, common in the Mountain limestone, Oolite, and Greensand formations, and often contains petrifactions, as shells, corals, and wood

Other siliceous minerals seem intimate mixtures of quartz and opal as —

Flint greyish white, grey, or greyish black, also yellow, red, or brown, sometimes in clouds, spots, or stripes, semitransparent, lustre dull fracture flat conchoidal, occurs chiefly in the Chalk formation as in England, Ireland, Aberdeenshire France, Germany, and other countries, sometimes in beds or vertical veins, often in irregular lumps or concretions, inclosing petrifactions, as sponges echinoids, shells, or siliceous *Infusoria* The colour is partly derived from carbon or organic matter Used formerly for gun flints and still for the manufacture of glass and pottery, and cut into cameos or other ornaments

Chalcedony semitransparent or translucent white, grey, blue, green, yellow, or brown stalactitic, reniform or botryoidal, and in pseudomorphs or petrifactions, Iceland Faroes, Trevascus in Cornwall, Scotland, Hungary Bohemia, Oberstein *Carnelian* chiefly blood red but also yellow, brown or almost black, India, Arabia Surinam and Siberia, also Bohemia, Saxony, and Scotland (Fifeshire) *Plasma* leek or grass green, and waxy lustre, Olympus Black Forest India and China

Chrysoprase apple green, Silesia and Vermont in North America. *Moss Agate* and *Heliotrope* dark green and dendritic (called *Bloodstone* when sprinkled with deep red spots), India Siberia, Bohemia, Fassa Valley island of Rum and other parts of Scotland

136 TRIDYMITE, SiO$_2$

Hexagonal, P middle edge 124° 4, polar edges 127° 35 Single crystals very minute hexagonal tables of 0P, ∞P but with the edges replaced by P and ∞P2, are rare (fig 314) Mostly twinned in double or (oftener) triple combinations (figs. 315 to 317) Cl basal, indistinct, fracture conchoidal H = 7, G = 2 282 to 2 326 Colourless and transparent, vitreous, pearly on the base B B like quartz C c 96 silica, with some alumina, magnesia, and iron peroxide, probably from the matrix Discovered by Von Rath in the trachyte of San Cristobal, near Pachuca, in Mexico, also in the trachyte of Mont Dore (Puy de Dôme), the Drachenfels, and Hungary Many opals, treated with solution of potash, leave crystals, as those from Zimapan, Kaschau, Silesia, and the cacholong from Iceland Where such crystals are abundant, the opal becomes opaque or snow white Jenzsch regards these as still another variety of silica

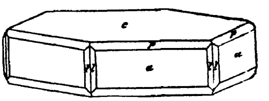


Fig 314

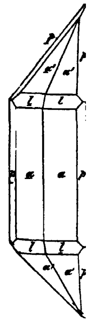


Fig 315

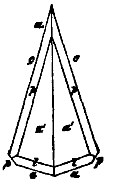


Fig 316

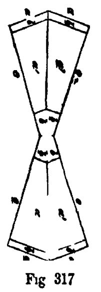


Fig 317

137 **Opal**, $9SiO_2$, H_2O to $3SiO_2$ H O

Amorphous, fracture conchoidal, very brittle H = 5 5 to 6 5, G = 2 to 2 2 Transparent to opaque vitreous, inclining to resinous Colourless, but often white, yellow, red, brown, green, or grey, with a beautiful play of colours B B decrepitates and becomes opaque, but is infusible in the closed tube yields water, almost wholly soluble in solution of potash C c silica with 5 to 13 per cent water Most opals are mixtures of various minerals

The following varieties may be noticed —(1) *Hyalite, Glassy Opal,* or *Müller s Glass* transparent colourless, very glassy, small botryoidal, or incrusting Kaiserstuhl in the Breisgau Schemnitz, Silesia, Moravia, Mexico, and other places (2) *Fire Opal* or *Girasol* transparent, brilliant vitreous lustre, bright hyacinth red or yellow, Zimapan in Mexico, and the Faroes (3) *Noble Opal,* semi transparent or translucent, resinous, inclining to vitreous, bluish or yellowish white, with brilliant prismatic colours, most show double refraction and are binaxal, in irregular masses or veins near Eperies in Hungary, Australia (4) *Common Opal* semitransparent, vitreous, white yellow, green, red, or brown, Hungary also Faroes, Iceland, the Giant s Causeway, and the Western Isles of Scotland (5) *Semi opal* duller and less pellucid, *Wood Opal* or *Lithoxylon* with the form and texture of wood distinctly seen, Hungary, Bohemia, and other countries (6) *Menilite* compact reniform, opaque and brown or bluish grey Menilmontant, near Paris (7) *Opal Jasper* blood red brown, or yellow (8) *Cacholong* opaque, dull, glimmering, or pearly, and yellowish or rarely reddish white, in veins or reniform and incrusting, Faroes, Iceland, the Giant's Causeway One variety is named *Hydrophane,* from imbibing water, and becoming translucent (9) *Siliceous Sinter* deposited from the Geyser and other hot springs and *Pearl Sinter* incrusting volcanic tufa at Santa Fiora in Tuscany (*Fiorite*), and in Auvergne

138 **Zircon**, ZrO_2, SiO_2

Pyramidal, P 84° 20 Crystals, ∞P, P often with 3P3 also ∞P∞, P, or ∞P∞ (*s*), ∞P (*l*), P (*P*) 3P3 (*x*), P∞ (*t*), 4P4 (*y*), 5P5 (*z*) (fig 318, also 86, 87, 585) Chiefly prismatic or pyramidal, and in rounded grains Transparent to opaque, vitreous, often adamantine Rarely white, generally grey, yellow, green, or frequently red and brown B B loses its colour, but is infusible Not affected by any acid except concentrated s acid, after long digestion C c 66 3 zirconia and 33 7 silica, with 0 to 2 iron peroxide as colouring matter Miask, Arendal, Sweden, Belgium (at Nil St Vincent) Carinthia Tyrol Ceylon and North America, in Scotland, Scalpay in Harris (fig 319) Lewis (*Hyacinth*), Sutherland, Ross The colourless varieties are sold for diamonds The more brilliantly coloured are named hyacinths, and are valuable gems

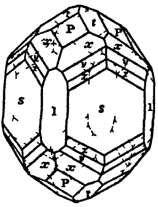


Fig 318

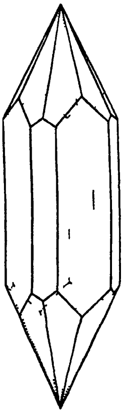


Fig 319 (sp 138)

SULPHIDES, SELENIDES TELLURIDES, &c

139 **Pyrite**, FeS_2

Cubic, semitesseral dominant (figs 320 to 323, also 67 to 77 and 26 to 34) Pentagonal dodecahedron in excess or striæ, produced by oscillation of it with faces of the cube, visible Often distorted, as in the cubo octahedral twin (fig 323) Sometimes massive and in pseudomorphs Cl cubic or octahedral, difficult, brittle H = 6 to 6 5, G = 4 9 to 5 2 Brass yellow, often somewhat gold yellow, streak brownish black when broken emits smell of sulphur In closed tube sulphur sublimes B B on charcoal burns with blue flame, and odour of sulphurous acid In inner flame fuses to magnetic bead Sol in n acid with deposition of sulphur C c iron 46 7, sulphur 53 3, often contains gold in visible grains, when broken Common to rocks of all ages Tomnadashin, Birnam, Scotland, Cornwall, England, Elba and Traversella, Peru; Rossie, Middletown, and Schoharie in U S Auriferous pyrites, Berezoff (Siberia), Adelfors (Sweden), Mexico. Used to be cut in facets and set as an ornament, under the name of marcasites, also for striking fire in the old firelocks, whence the name of firestone, now used for manufacture of sulphuric acid

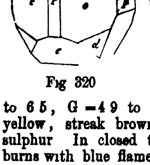


Fig 320

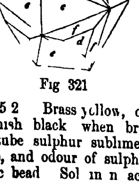


Fig 321

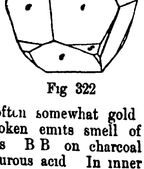


Fig 322

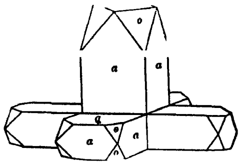


Fig 323 (sp 139)

140 **Marcasite**, FeS_2

Right prismatic, ∞P (*M*) 106° 5 Crystals tabular, thin prismatic, or pyramidal Twins very frequent, also cockscomb like groups, or spherical and stalactitic Cl ∞P fracture uneven, brittle G = 4 65 to 4 9 Greyish bronze yellow to greenish grey, often with brown crust, streak greenish grey or brownish black B B, &c, like pyrite Very prone to decomposition, being changed into green vitriol, which may be detected by the tongue *Spear Pyrites* are twins like fig 325 Littmitz, Przibram *Hepatic Pyrites* or *Leberkies,* liver-brown, generally decomposing, Harz, Saxony, Sweden *Cockscomb Pyrites,* Derbyshire and the Harz *Kyrosite* contains arsenic

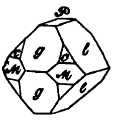


Fig 324

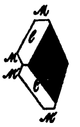


Fig 325

141 **Mispickel**, $FeS_2 + FeAs$

Right prismatic, ∞P (*M*) 111° 12 (fig 326) Twins common, also massive or columnar Cl ∞P, fracture uneven, brittle H = 5 5 to 6, G = 6 to 6 2 Silver white to steel grey, streak black In closed tube yields first a red then a brown sublimate, lastly metallic arsenic B B on charcoal fuses to a black magnetic globule Sol in n acid, with separation of arsenious acid and sulphur C c 34 3 iron, 46 1 arsenic, 19 6 sulphur, sometimes silver or gold, or 5 to 9 of cobalt Cornwall, Freiberg, Zinnwald, Sweden, Franconia, America.

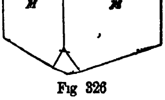


Fig 326

142 **Leucopyrite**, FeAs

Right prismatic, ∞P (*d*) 122° 26, $\bar{P}\infty$ (*o*) 51° 20 Crystals like fig 327, generally massive or columnar Cl basal, fracture uneven, brittle H = 5 to 5 5 G = 7 to 7 4 Silver white with darker tarnish, streak greyish black B B emits strong smell of arsenic, and fuses to a black magnetic globule C c iron 27 2, arsenic 72 8, sometimes iron 32 2 and arsenic 66 8, always some sulphur, and often nickel and cobalt Fossum in Norway, Andreasberg, Styria, and Silesia *Spathiopyrite,* from Bieber in Hesse, seems a variety

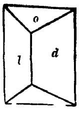


Fig 327

143 **Cobaltite**, $CoS_2 + CoAs$

Cubic and hemihedral, sometimes massive (figs 67, 74) Cl cubic perfect, brittle H = 5 5, G = 6 to 6 3 Brilliant lustre Pinkish silver white, tarnishes yellow or grey, streak greyish black B B with borax blue glass, evolves smell of arsenic C c cobalt 35 9, arsenic 44 9, sulphur 19 2 St Just in Cornwall, Tunaberg in Sweden, Skutterud in Norway, Querbach in Silesia

144 **Glaucodote**, $(Co, Fe)S_2 + (Co, Fe)As_2$

Right prismatic, ∞P 112° 36 Cl basal, perfect H = 5, G = 6 Lustre metallic Greyish white, streak black C c cobalt 24 7, iron 11 9, arsenic 43 2, sulphur 20 2 Huasco in Chili

145 **Smaltine**, $(Co, Fe, Ni) As_2$

Cubic, generally like fig 27, also reticulated and granular compact Cl octahedral, fracture uneven, brittle H = 5 5, G = 6 4 to 7 3 Tin white to steel grey, with dark or iridescent tarnish, streak greyish black Evolves odour of arsenic, when broken or heated C c 71 4 arsenic, 28 6 cobalt, sometimes 3 to 19 iron, and 1 to 12 nickel, or 4 bismuth Dolcoath and Redruth in Cornwall, Schneeberg, Annaberg, Tunaberg, Allemont, Chatham in Connecticut

146 **Chloantite** (*White Nickel*), $NiAs_2$.

Cubic, generally fine granular or compact; fracture uneven, brittle H = 5 5, G = 6 4 to 6 6 Tin white, rapidly tarnishing black In the closed tube yields a sublimate of arsenic, and becomes copper red Gives odour of arsenic when broken B B fuses with much smoke, becomes coated with crystals of arsenious acid, and leaves a brittle grain of metal C c 28 2 nickel, 71 8 arsenic, but often with cobalt Schneeberg, Riechelsdorf, Allemont, Chatham in Connecticut

147 **Gersdorffite**, NiS_2+NiAs_2

Cubic (figs 74, 30, 26) Cl cubic, generally granular H = 5 5, G = 6 67 Lustre metallic Silver white to steel grey, decrepitates in closed tube B B fuses to a black slag, partially sol in n acid C c 35 2 nickel, 45 4 arsenic, and 19 4 sulphur, sometimes with cobalt Craignuin, near Loch Fyne, with 23 nickel and 6 cobalt The Harz, Sweden, Spain, and Brazil

148 **Ullmannite**, $NiSb+NiS_2$

Cubic (figs 31, 29, 27), often tetrahedral, and in twins as in figs 328, 329 Cl cubic, perfect, fracture uneven H = 5 to 5 5, G = 6 2 to 6 5 Lead grey to tin white, often with iridescent tarnish B B fuses with dense fumes Sol in n acid C c 27 4 nickel, 57 5 antimony, and 15 1 sulphur Westerwald, Siegen, Harzgerode, Lolling (Carinthia), Lobenstein, and Bleiberg

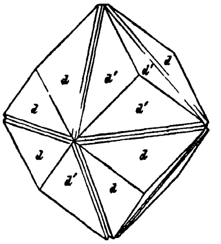


Fig 328

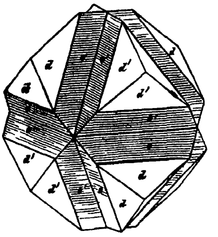


Fig 329

149 **Rammelsbergite**, $NiAs$

Right prismatic, ∞P 123° to 124° Chiefly massive, or in radiating and botryoidal aggregates H = 5, G = 7 2 Colour tin white Schneeberg, Reichelsdorf, and Wittichen in Baden

150 **Hauerite**, MnS_2

Cubic (figs 30, 30–26, 30–33–37) Crystals single or in spherical groups Cl cubic, perfect, H = 4, G = 3 46 Reddish brown to brownish black, streak brownish red In closed tube yields sulphur, and leaves a green mass, which is sol in h acid C c 46 manganese and 54 sulphur Kalinka in Hungary

151 **Pyrrhotite** (*Magnetic Pyrites*), Fe_7S_8

Hexagonal, P 126° 48 Crystals rare, sometimes hemihedral on $z\frac{1}{2}$, commonly massive or granular Cl ∞P, imperfect, brittle H = 3 5 to 4 5, G = 4 5 to 4 6 Colour bronze yellow with pinchbeck brown tarnish, streak greyish black More or less magnetic. C c 63 65 iron and 36 35 sulphur, sometimes with nickel Common in primary limestones and diorites of Scotland Crystallized in above forms at Askaig on Loch Shin, Sutherland, Carnarvon, Cornwall, Fahlun, Bodenmais, Andreasberg Distinguished by its colour and its solubility in h acid

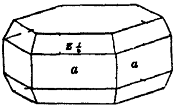


Fig 330

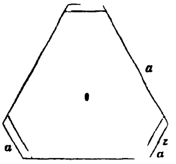


Fig 331

152 **Linnæite**, $2(Co, Cu)S+CoS_2$

Cubic (figs 29, 30), often twinned, twin face O, also massive Cl cubic, brittle H = 5 5, G = 4 9 to 5 Silver white, with a yellow tarnish, streak blackish grey B B fuses to a grey magnetic globule, which is bronze yellow when broken C c cobalt 43 2, copper 14 4, iron 3 5, sulphur 38 5 Bastnaes (Sweden)

153 **Siegenite**, $CoS+Ni_2S_3$ (?)

Cubic, generally in crystals like fig 29, also massive Colour silver-white, inclining to pink Other features like linnæite C c cobalt 40 8, nickel 14 6, sulphur 43 1 Musen near Siegen, Maryland, and Missouri The American mineral has 30 5 of nickel

154 **Polydymite**, Ni_4S_5

Cubic, in minute octahedral crystals and flattened twins Cl cubic H. = 4 5, G = 4 81 C c 39 45 nickel, 40 55 sulphur, but generally with 4 of iron Westphalia *Saynite* or *grunauite* seems to be a bismuthic and cobaltic variety, it is from Grunau in Sayn Altenkirchen

155 **Byrichrite**, $3NiS+2NiS_2$

H = 3 to 3 5, G = 4 7 C c 54 23 nickel, 2 79 iron 42 86 sulphur From the Westerwald

156 **Horbachite**, $4Fe_2S_3+Ni_2S_3$

Crystalline masses H = 4 5, G = 4 43 to 4 7 Colour pinchbeck brown, streak black C c nickel 11 98, iron 41 96, sulphur 45 87 Horbach in the Black Forest

157 **Skutterudite**, $CoAs_3$

Cubic (figs 30, 26 with 33, 40) and granular Cl cubic, fracture conchoidal, brittle H = 6, G = 6 74 to 6 84 Tin white to lead grey Lustre brilliant In closed tube gives sublimate of metallic arsenic, otherwise like smaltine C c 79 arsenic, 21 cobalt Skutterud, near Modum in Norway

158 **Galena**, PbS

Cubic, crystals chiefly cube, octahedron, and rhombic dodecahedron, rarely 2O and 2O2 Also massive and granular, compact, or laminar, and in pseudomorphs of pyromorphite and other minerals Cl cubic, very perfect, fracture scarcely observable, sectile H = 2 5, G = 7 2 to 7 6 Lead grey, with darker or rarely iridescent tarnish, streak greyish black B B decrepitates, fuses, and leaves a globule of lead Sol in n acid C c 86 7 lead, and 13 3 sulphur, but usually contains a little silver, ranging from 1 to 3 or 5 parts in 10,000, rarely 1 per cent or more Some contain copper, zinc, or antimony, others selenium, and others (the 'supersulphuret) probably free sulphur (2 to 8 per cent) Most common ore of lead in many countries Leadhills, Pentland Hills, Linlithgow, Inverkeithing, Monaltrie, Tyndrum, Strontian, Islay, Orkney, Cornwall, Derbyshire (Castletown), Cumberland (Alston Moor), Durham (Allenhead), Wales, Isle of Man

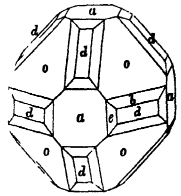


Fig 332

159 **Cuproplumbite**, $2PbS+Cu_2S$

Cubic H = 2 5, G = 6 4 Bluish grey Chili

160 **Beegerite**, $6PbS+Bi_2S_3$

Cubic G = 7 27 Cl cubic Light to dark grey Lustre brilliant C c sulphur 15, bismuth 20 6 lead 64 2, with copper 1 7 Grant (Park county, Colorado)

161 **Clausthalite**, $PbSe$

Cubic, but massive granular H = 2 5 to 3, G = 8 2 to 8 8 Lead grey, streak grey B B fuses, smells of selenium, colours the flame blue stains the support red, yellow, and white, and volatilizes, except a small residue, without fusing C c 72 7 lead, 27 3 selenium, but sometimes 11 7 of silver Zorge Lerbach, and Clausthal in the Harz *Tilkerodite*, or *Selen Cobalt Blei*, containing 3 per cent of cobalt, from Tilkerode, is a variety

162 **Zorgite**

Massive granular, like clausthalite, but inclining to reddish, and often tarnished There are four varieties (*a*) *Selen Blei Kupfer* G = 7 4 to 7 5 $5PbSe+CuSe$, with 4 copper, 65 lead, 30 selenium (*b*) The same, but with G = 5 6, 4Pb, 4Cu, 7Se, with 15 8 copper, 48 4 lead, and 35 selenium (*c*) *Selen Kupfer Blei* with G = 7, $2PbSe+CuSe$, with 8 copper 57 lead, and 32 selenium (*d*) $2PbSe+9CuSe$ with 46 64 copper, 16 58 lead, and 36 59 selenium From Tilkerode and Zorge in the Harz, and near Gabel in Thuringia

163 **Altaite**, $PbTe$

Cubic and granular, fracture uneven, sectile H = 3 to 3 5 G = 8 1 to 8 2 Tin white to yellow, with yellow tarnish B B colours the flame blue, fusing to a globule, which almost wholly volatilizes C c 61 9 lead and 38 1 tellurium Zavodinski in the Altai, California, Colorado, and Chili

164 **Redruthite** (*Copper Glance*), Cu_2S

Right prismatic ∞P (*o*) 119° 35, P (*P*) middle edge 125° 22 $\frac{1}{3}\breve{P}$ (*a*) middle edge 65° 40, $2\breve{P}\infty$ (*d*) middle edge 125° 40, $\frac{2}{3}\breve{P}\infty$ (*e*) middle edge 65° 48 Crystals 0P (*s*), ∞P (*o*), $\infty\breve{P}\infty$ (*p*) (figs 333, 334), with hexagonal aspect, also twins, and massive Cl ∞P, imperfect fracture conchoidal or uneven, sectile H = 2 5 to 3,

Fig 333.

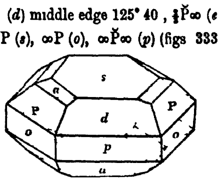


Fig 334

G = 5 5 to 5 8 Rather dull, brighter on the streak Blackish lead grey, with a blue or other tarnish B B colours the flame blue, on charcoal in the oxygen flame sputters, and fuses easily, in the red flame becomes solid With soda gives a grain of copper Green solution in n acid, leaving sulphur C c 79 8 copper, 20 2 sulphur Fassnet Burn (Haddingtonshire), Ayrshire, Fair Island, near Redruth and Land s End in Cornwall, Saxony, Silesia, Norway, the Banat, Siberia and the United States Important copper ore

165 STROMEYERITE, $Cu_2S + AgS$

Right prismatic, isomorphous with redruthite Crystals rare, usually massive, fracture flat, very sectile H = 2 5, G = 6 2 to 6 3 Bright Blackish lead grey C c 53 1 silver, 31 2 copper, and 15 7 sulphur, but often indeterminate proportions of silver (3 to 53) and copper (30 to 75) Schlangenberg in Siberia, Rudelstadt in Silesia, and Catemo in Chili

166 BERZELINITE, Cu_2Se

Crystalline, in thin dendritic crusts, and imbedded in calcite Silver white with a black tarnish, streak shining In open tube gives a red sublimate of selenium with white crystals of selenious acid B B on charcoal fuses to a grey slightly malleable bead, giving odour of selenious acid, with soda a grain of copper C c 61 5 copper and 38 5 selenium Skrikerum in Småland, Lerbach in the Harz

167 CROOKESITE $(CuTl)_2Se$

In crystalline grains the size of peas H = 2 5 to 3, G = 6 9 Brittle Lead grey Metallic B B colours the flame intense green C c 45 76 copper, 3 71 silver, 17 25 thallium, 33 2 selenium From Skrikerum

168 EUKAIRITE $Cu_2Se + AgSe$

Massive and granular crystalline Cuts with knife Lead grey streak shining B B fuses to a brittle metallic grain C c 43 1 silver, 25 3 copper, and 31 6 selenium Skrikerum, Atacama, Chili

169 ARGENTITE, Ag_2S

Cubic ∞O∞, O, ∞O and 2O2 (figs 29, 56) Crystals generally misshapen, with uneven or curved faces, in druses or linear groups, also arborescent, capillary, or in crusts Cl indistinct fracture hackly, malleable and flexible H = 2 to 2 5, G = 7 to 7 4 Partly brilliant more so on the streak Blackish lead grey often with a black brown, or rarely iridescent tarnish B B on charcoal fuses, intumesces greatly and leaves a grain of silver Sol in con n acid C c 87 silver and 13 sulphur Huel Duchy, Dolcoath Herland, and near Callington in Cornwall, Alva in Stirlingshire Freiberg Marienberg, Annaberg, Schneeberg, Johann Georgenstadt, Joachimsthal, Schemnitz and Kremnitz, Kongsberg Common ore at Guanajuato and Zacatecas in Mexico, in Peru, and at Blagodat in Siberia

170 ACANTHITE, AgS

Right prismatic H = 2 5 G = 7 33 Iron black C c like argentite, thus dimorphous Freiberg and Clausthal, on argentite, also at Copiapo

171 JALPAITE, $3AgS + Cu_2S$

Cubic form O Cl cubic, malleable H = 2 5 G = 6 88 Dark grey Metallic lustre C c silver 71 78, copper 14 04, sulphur 14 2 Jalpa in Mexico

172 LAUTITE $(CuAg) AsS$

Granular Iron black H = 3 G = 4 96 C c copper 28 3, silver 12, arsenic 41 8, sulphur 17 86 Lauta, near Marienberg

173 NAUMANNITE, $AgSe$

In thin plates and granular Cl hexahedral, perfect Malleable H = 2 5, G = 8 Iron black Splendent C c 73 silver and 27 selenium, with 4 91 lead Tilkerode

174 HESSITE, $AgTe$

Cubic or anorthic (?), massive and granular Slightly malleable H = 2 5 to 3, G = 8 1 to 8 45 Blackish lead grey to steel grey B B on charcoal fumes, fuses to a black grain with white spots and leaves a brittle grain of silver C c 6 8 silver and 37 2 tellurium Zavodinski (Altai) Nagyag, Retzbanya California and Chili

175 PETZITE $2AgTe + AuTe$

Like hessite Two varieties — (*a*) with G = 8 72 containing 18 per cent of gold, from Nagyag (*b*) with G = 9 to 9 4, and 24 to 26 of gold Calaveras and Tuolumne in California, Colorado

176 DISCRASITE, Ag_2Sb, Ag_3Sb and Ag_6Sb

Right prismatic, P with polar edges 1 2° 42 and 92°, ∞P 120° nearly (figs. 335, 336). Crystals short prismatic, or thick tabular, and vertically striated (fig 335), twins united by a face of ∞P, often in stellar groups (fig 336), also massive or granular Cl, basal and P̆∞, distinct, ∞P imperfect, rather brittle, and slightly malleable H = 3 5, G = 9 4 to 9 8 Silver white to tin white, with a yellow or blackish tarnish B B fuses easily, fumes staining the charcoal white, and leaves a grain of silver Sol in n acid C c 64 to 84 silver, and 36 to 16 antimony Andreasberg, Allemont in Dauphiné, Spain, and Arqueros in Coquimbo (Chili) A valuable ore of silver A variety from Chili contains 94 2 silver and 5 8 antimony, and is $Ag_{18}Sb$

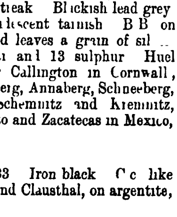


Fig 335 (sp 176)

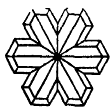


Fig 336

177 BLENDE, ZnS

Cubic and tetrahedral (figs 152, 153, 337) Twins remarkably common, united by a face of O, and several times repeated, frequently massive and granular Cl ∞O, perfect, very brittle H = 3 5 to 4 G = 3 9 to 4 2 Semitransparent to opaque, adamantine and resinous Brown or black, also red, yellow, and green, rarely colourless or white B B decrepitates, often violently, but only fuses on very thin edges Sol in con n acid, leaving sulphur C c 67 zinc and 33 sulphur, but generally in the darker varieties with 1 to 15 iron, 0 to 3 cadmium Very abundant Glen Gairn (bright yellow and highly phosphorescent), Leadhills Tyndrum, Cornwall Derbyshire Cumberland, the Harz Freiberg, Przibram, Schemnitz, Kapnik, North America Peru Used for producing zinc vitriol and sulphur, and as an ore of zinc Lithium, indium, thallium, and gallium have all been found in blende

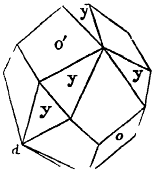


Fig 337

178 WURTZITE, $6ZnS + FeS$

Hexagonal, ∞P, P, with well marked horizontal striæ Cl basal, and prismatic H = 3 5 to 4, G = 3 9 to 4 1 Brownish black, streak light brown C c like blende which is thus dimorphous Oruro in Bolivia, and Przibram (radiated and cadmiferous)

179 GREENOCKITE, CdS

Hexagonal and generally hemimorphic P 86° 21′, 2P 123° 54 Crystals 2P 0P, ∞P, P, or P, 2P, ∞P, attached singly Cl ∞P, imperfect, basal perfect H = 3 to 3 5, G = 4 8 to 4 9 Translucent brilliant resinous, or adamantine Honey or orange yellow, rarely brown, streak yellow B B decrepitates, and becomes carmine red, but again yellow when cold, fused with soda forms a reddish brown coating on charcoal Sol in h acid C c 77 6 cadmium, and 22 4 sulphur Bishopton in Renfrewshire, Przibram, and Friedensville in Pennsylvania

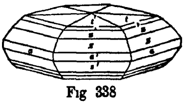


Fig 338

180 ALABANDINE, MnS

Cubic, O and ∞O∞, usually massive and granular Cl hexahedral, perfect, fracture uneven, rather brittle H = 3 5 to 4, G = 3 9 to 4 Opaque, semi metallic Iron black to dark steel grey, brownish black tarnish, streak dark green B B fuses on thin edges to a brown slag Sol in h acid C c 63 manganese and 37 sulphur Nagyag, Kapnik, Alabanda in Caria, Mexico, and Brazil

181 MILLERITE, NiS

Hexagonal rhombohedral, R 144° 8′, in fine acicular prisms of ∞P2, R Brittle H = 3 5, G = 4 6 (or 5 26 to 5 65) Brass or bronze yellow, with a grey or iridescent tarnish B B fuses easily to a blackish metallic globule, which boils and sputters In nitro hydrochloric acid forms a green solution C c 64 4 nickel and 35 6 sulphur Morven (Argyllshire), Chapel (Fife), Ayrshire, near St Austell in Cornwall, at Merthyr Tydvil, Johann Georgenstadt, Joachimsthal, Przibram, Camsdorf, Riechelsdorf, Pennsylvania

182 PENTLANDITE (*Eisennickelkies*), $2FeS + NiS$

Cubic, massive and granular, fracture uneven, brittle H = 3 5 to 4, G = 4 6 Light pinchbeck brown, with darker streak Not magnetic B B acts in general like pyrrhotite, the roasted powder forms with borax in the red flame a black opaque glass C c 36 sulphur, 42 iron, and 22 nickel, but mixed with pyrrhotite and chalcopyrite Lillehammer in southern Norway *Inverarite*, $5FeS + NiS$, with 11 of nickel, from near Inveraray, is a variety

183 NICKELITE (*Copper Nickel*), $NiAs$

Hexagonal, P 86° 50 Crystals ∞P, 0P, rare. Arborescent, reniform, and massive, fracture conchoidal and uneven, brittle H = 5 5, G = 7 5 to 7 7 Light copper red, with a blackish tarnish It forms no sublimate in the closed tube B B. fuses with strong umes to a white, brittle, metallic globule C c 43 6 nickel and 56 4 arsenic Hilderston in Linlithgow, Pibble in Kirkcudbright, Leadhills, Pengelly and Huel Chance in Cornwall, Freiberg, Schneeberg, Joachimsthal, Sangerhausen, Andreasberg, Chatham in Connecticut Used as an ore of nickel

184 BREITHAUPTITE (*Antimonial Nickel*), NiSb

Hexagonal, P 86° 56 Crystals, thin striated hexagonal tables of 0P, ∞P H = 5, G = 7 5 to 7 6 Brilliant Light copper red, generally with violet tarnish B B fumes, but fuses with great difficulty C c 32 2 nickel and 67 8 antimony Andreasberg

185 STANNITE (*Tin Pyrites*), $\mathrm{2CuS, SnS_2 + 2(FeS, ZnS) + SnS_2}$

Cubic, in cubes very rare, generally massive and granular Cl hexahedral, imperfect, fracture uneven or small conchoidal, brittle H = 4, G = 4 3 to 4 5 Steel grey, streak black. C c 26 to 32 tin, 24 to 30 copper, 5 to 12 iron, 2 to 10 zinc and 30 sulphur Huel Rock near St Agnes St Michael s Mount and Carn brea in Cornwall, Zinnwald Bell metal ore

186 STERNBERGITE, $\mathrm{(AgS + 2FeS)FeS_3}$

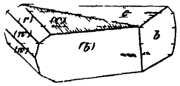


Fig 339

Right prismatic, P middle edge 118° Crystals usually thin tabular, in twins, or in fan like and spheroidal groups Cl basal, perfect, sectile, and flexible in thin laminæ H = 1 to 1 5, G = 4 2 to 4 25 Dark pinchbeck brown, often a violet blue tarnish streak black C c 34 2 silver 35 4 iron and 30 4 sulphur Joachimsthal, Schneeberg, and Johann Georgenstadt *Flexible Sulphuret of Silver*, from Hungary and Freiberg, is identical *Frieseite*, $\mathrm{Ag_2Fe_5S_8}$ in twins (fig 339), is a variety

187 RITTINGERITE, AgAs

Oblique prismatic ∞P 126° 18, ∞P∞ and 0P Cl basal, fracture conchoidal brittle H = 2 5 to 3, G = 5 63 C c silver 57 7, the remainder being arsenic, with some selenium Joachimsthal, Silesia, Felsobanya in Hungary

188 COVELLINE, CuS

Hexagonal Crystals ∞P, 0P, rare usually reniform and granular Cl basal sectile Thin laminæ flexible H = 1 5 to 2, G = 3 8 to 4 6 Resinous Indigo blue, streak black B B burns with blue flame Sol in n acid C c 66 7 copper, 33 3 sulphur Cairnbeg in Cornwall, Vesuvius, Leogang (Austria), Chili, Angola, New Zealand, and Victoria

189 CHALCOPYRITE (*Copper Pyrites*), $\mathrm{CuS + FeS}$

Pyramidal and sphenoidal hemihedric, ½P (*P*) with polar edges 71° 20, ∞P∞ Crystals generally small and deformed twins very common like fig 340 P∞ (*b*) 89° 10, 2P∞ (*c*) 126° 11, 0P (*a*) P (fig 89) Most commonly compact and disseminated, also botryoidal and reniform Cl pyramidal 2P∞ sometimes rather distinct, fracture conchoidal or uneven H = 3 5 to 4 G = 4 1 to 4 3 Brass yellow, often with a gold yellow or iridescent tarnish (peacock copper ore), streak greenish black B B on charcoal becomes darker or black, and on cooling red, fuses easily to a steel-grey globule, which at length becomes magnetic brittle and greyish red on the fractured surface, with borax and soda yields a grain of copper, moistened with h acid, colours the flame blue C c essentially 1 atom copper, 1 atom iron, and 2 atoms sulphur, with 34 5 copper 30 5 iron, and 35 sulphur The most abundant ore of copper In Kirkcudbrightshire and Wigtownshire, Tyndrum in Perthshire Inverness shire, Lairg in Sutherland, Shetland, Anglesea (Parys mine), Derbyshire, Staffordshire, Cumberland, Gunnislake (Devonshire), St Austell (Cornwall), Wicklow, Falun, Roraas, Freiberg, Mansfeld, Goslar, Lauterberg, Musen, Siberia It is distinguished from pyrite by yielding readily to the knife, by its tarnish, and by forming a green solution in n acid

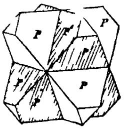


Fig 340

190 BORNITE (*Purple Copper*), $\mathrm{3Cu_2S, Fe_2S_3}$

Cubic Crystals ∞O∞, and ∞O∞, O, but rare, and generally rough or uneven, also twins Mostly massive Cl octahedral, fracture conchoidal, slightly brittle, sectile H = 3, G = 4 9 to 5 1 Colour between copper red and pinchbeck brown, with tarnish at first red or brown, then violet or sky blue, streak greyish black. B B acts like chalcopyrite Soluble in con h acid, leaving sulphur C c 55 6 copper, 16 4 iron, and 28 sulphur Crystals near Redruth and St Day in Cornwall, massive at Killarney in Ireland, also Norway, Sweden, Mansfeld, Silesia, Tuscany, and Chili An ore of copper

191 CUBAN, $\mathrm{CuS, Fe\ S_3}$

Cubic H = 4, G = 4·1 Bronze yellow, streak bronze yellow and black Barracanao in Cuba, Tunaberg and Kafveltorp in Sweden

192 DOMEYKITE, $\mathrm{Cu_6As}$

Botryoidal or massive, fracture uneven, brittle H = 3 to 3 5; G = 7 to 7 5 Tin or silver white, inclining to yellow, with an iridescent tarnish Not affected by h acid C c 71 63 copper and 28 37 arsenic Calabazo in Coquimbo, and Copiapo in Chili *Condurrite*, massive, seems an impure variety, from Condurrow mine and near Redruth (Cornwall) *Algodonite* from Lake Superior, *Whitneyite* from Mexico, and *Darwinite* (88 copper) are also identical or similar

193 MELONITE, $\mathrm{Ni_2Te_3}$

Hexagonal, minute tabular crystals foliated and granular. Metallic lustre Reddish white, streak dark grey C c nickel 21, silver 4 1, tellurium 73 4 Stanislaus and Calaveras (California)

194 SYLVANITE, $\mathrm{AgTe_4 + AuTe_2}$

Oblique prismatic, C 55° 21 ∞P 94° 26 −P∞ 19° 21′, P∞ 62° 43 Crystals small, short acicular and often twinned and grouped in rows like letters sectile, but friable H = 1 5 to 2, G = 7 99 to 8 33 Steel grey to silver white, and pale bronze yellow C c 59 6 tellurium, with 0 6 to 8 5 antimony, 26 5 gold (in some 30), and 13 9 silver with 0 2 to 15 lead Offenbanya (*Graphic Tellurium*), Nagyag (*Yellow Tellurium*) and California

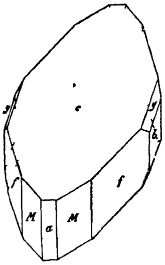


Fig 341

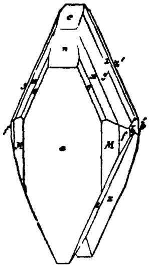


Fig 342

195 NAGYAGITE, *Black Tellurium*

Pyramidal P 137° 52, P∞ 122° 50 and 0P (fig 343) Crystals tabular, rare in general in thin plates or foliated Cl basal, perfect sectile, thin laminæ flexible H = 1 to 1 5, G = 6 85 to 7 2 Splendent Blackish lead grey C c 51 to 63 lead, 6 to 9 gold 1 copper and silver, 13 to 32 tellurium 3 to 12 sulphur, and 0 to 4 5 antimony Nagyag and Offenbanya in Transylvania

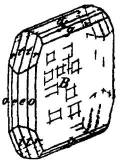


Fig 343 (sp 195)

196 MALDONITE, $\mathrm{Au_2Bi}$

H = 1 5 to 2, G = 8 2 to 9 7 Colour silver white, with black tarnish C c gold 64 5, bismuth 35 5 Occurs in granite veins at Maldon in Victoria.

197 CHILENITE, $\mathrm{Ag_{10}Bi}$

Minute plates of metallic lustre Silver white, but tarnished red or yellow Silver 83 9, bismuth 16 1 From the mine San Antonio near Copiapo in Chili.

198 CINNABAR, HgS

Hexagonal and rhombohedral, R 71° 48 R (*n*), 0R (*o*), ∞R (*m*). ⅔R (*i*) (fig 344) Crystals rhombohedral, also granular, compact, and earthy Cl ∞R, perfect, fracture uneven and splintery, sectile H = 2 to 2 5, G = 8 to 8 2 Transparent, with circular polarization Adamantine Cochineal red, streak scarlet C c 86 2 mercury, 13 8 sulphur Idria in Carniola, Almaden in Spain, Wolfstein in Bavaria, Saxony, Hungary, Tuscany, China, California, Mexico, Peru Chief ore of mercury. Also a pigment *Hepatic Cinnabar* is a bituminous mixture

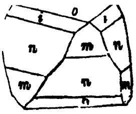


Fig 344

199 TIEMANNITE, HgSe

Fine granular, brittle H = 2 5, G = 7 1 to 7 4 Brilliant Dark lead grey C c 75 mercury, 25 selenium Clausthal and Zorge

200 LERBACHITE, $\mathrm{(PbHg)Se}$

Granular and massive G = 7 8 to 7 88 Colour steel grey to iron black Brittle Lerbach, Tilkerode in the Harz

201 GUANAJUATITE, $\mathrm{Bi_2Se_3}$

Massive, granular, foliated and fibrous H = 2 5 to 3 G = 6 25 Blue grey, streak grey and shining Metallic soft and malleable C c selenium 34 3, sulphur 7, bismuth 65 Santa Rosa (Guanajuato, Mexico)

202 **Coloradoite**, HgTe

Massive and granular H = 3, G = 8 63 Metallic Iron black Conchoidal fracture C c 61 mercury, 39 tellurium Colorado

203 **Molybdenite** MoS_2

Hexagonal (?) Crystals 0P, ∞P and 0P, ∞P, P Generally scaly Cl basal, perfect sectile and flexible Feels greasy H = 1 to 1 5, G = 4 6 to 4 9 Lead grey with red tinge, grey streak on paper, greenish on porcelain B B colours flame siskin green charcoal yields sulphurous fumes and forms a white coating in warm nitrochloric acid a greenish, and in boiling s acid a blue solution C c 59 molybdenum, 41 sulphur In granular limestones, and in granites in Sutherland, Ross, Aberdeen, Argyll, and Kirkcudbright, Shap in Westmoreland, Caldbeckfell in Cumberland, Arendal, Zinnwald, Mont Blanc, Maine, Connecticut, Yea in Victoria Used for preparing blue carmine, for colouring porcelain

Fig 345

204 **Laurite**, $(RuOs)_2S_3$

Cubic Crystals O ∞O∞, ∞O3, ∞O∞ Cl octahedral H = 7 5, G = 6 99 Metallic bright Dark iron black Powder grey Brittle C c ruthenium 65 18, osmium 3 03, sulphur 31 79 From platinum grains in Borneo and Oregon

205 **Realgar**, AsS

Oblique prismatic ∞P (*M*) 74° 26, P∞ (*n*) 132° 2, ∞P2 (*l*) 113° 16 Crystals (fig 346) generally prismatic, sometimes massive Cl basal, also clinodiagonal fracture splintery, sectile H = 1 5 to 2, G = 3 4 to 3 6 Transparent to opaque resinous Aurora red, streak orange yellow C c arsenic 70, sulphur 30 Nagyag Felsobanya, St Gotthard, Vesuvius

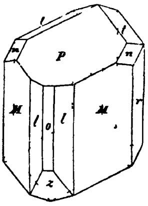


Fig 346 (sp 205)

206 **Orpiment**, As_2S_3

Right prismatic ∞P 117° 49 Frequently foliated Cl brachydiagonal, striated vertically, sectile and flexible H = 1 5 to 2, G = 3 4 to 3 5 Semi-transparent, resinous to pearly Citron yellow and orange yellow C c arsenic 61 sulphur 39 Servia, Kapnik, Andreasberg, Solfatara, Zimapan in Mexico

207 **Dimorphite**, As_2S_3

Right prismatic H = 1 5, G = 3 58 Orange yellow Solfatara

208 **Stibnite** Sb_2S_3

Right prismatic P polar edges 109° 26 and 108° 21′, ∞P 90° 54′ Crystals (fig 347) generally prismatic Cl brachydiagonal, perfect sectile H = 2, G = 4 6 to 4 7 Brilliant lead grey, often tarnished C c antimony 71 8, sulphur 28 2 Marsley Banffshire Harehill, Ayrshire Glenluming Dumfriesshire, Endellion and Padstow, Cornwall Wolfsberg Harz, Przibram, Schemnitz, Auvergne Spain America, Melbourne Chief ore of antimony

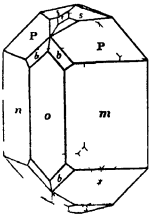


Fig 347 (sp 208)

209 **Bismuthine** Bi_2S_3

Right prismatic ∞P 91° 30 Crystals prismatic, striated also granular and foliated Cl brachydiagonal sectile H = 2 to 2 5 G = 6 4 to 6 6 Lead grey C c 81 2 bismuth 18 8 sulphur Caldbeckfell (Cumberland), Redruth (Cornwall), Riddarhyttan and Bastnaes (Sweden), Altenberg, Haddam (Connecticut), Ballarat (Victoria), Bolivia

210 **Frenzelite**, $Bi\,Se_3$ or $2Bi_2Se_3 + Bi_2S_3$

Right prismatic ∞P 90° Needle crystals, and massive Cl brachydiagonal H = 2 5 to 3, G = 6 25 Bluish grey, streak greyish black shining Lustre metallic Malleable C c bismuth 67 38 selenium 24 13 sulphur 6 6 Guanajuato (Mexico)

SULPHUR SALTS

211 **Guejarite** $Cu\,S + 2Sb\,S_3$

Right prismatic ∞P 101° 9 Cl brachydiagonal H = 3 5, G = 5 03 Steel green with bluish streak C c copper 15 5 antimony 58 5, sulphur 25 Guejar in Sierra Nevada

212 **Miargyrite**, $AgS + SbS_3$

Oblique prismatic, C 81° 36′ P 90° 53′, −P 59° 59′ Crystals pyramidal, or tabular (fig 348) massive, sectile H = 2 to 2 5, G = 5 2 to 5 3 Metallic adamantine Blackish lead grey to steel grey, streak cherry red C c 37 silver, 41 antimony, 22 sulphur. Freiberg, Przibram, Potosi

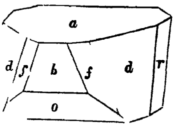


Fig 348 (sp 212)

213 **Morocochite** (*Silber Wismuth Glanz*), $AgS + BiS_3$

Massive Colour grey, streak light green G = 6 92 C c silver 28 3, bismuth 54 7, sulphur 17 Morococha in Peru

214 **Sartorite**, $PbS + As_2S_3$

Right prismatic Crystals slender, ∞P 123° 20′ Cl 0P H = 3, G = 5 39 C c lead 42 68, arsenic 30 93, sulphur 26 39 Binnenthal in Switzerland

215 **Zinckenite**, $PbS + SbS_3$

Right prismatic ∞P (*d*) 120° 39′, P̆∞ (*o*) 150° 36 (fig 349) Crystals acicular, vertically striated, and twinned 3 or 6 Sectile H = 3 to 3 5, G = 5 3 to 5 35 Steel grey to lead grey, with blue tarnish C c lead 35 9, antimony 42, sulphur 22 1 Wolfsberg

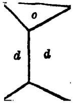


Fig 349 (sp 215)

216 **Emplectite**, $CuS + Bi_2S_3$

Right prismatic Tin white Saxony, Wurtemberg, and Copiapo

217 **Wolfsbergite**, $CuS + Sb\,S_3$

Right prismatic ∞P 135° 12, ∞P̆2 111° Crystals tabular, also fine granular Cl brachydiagonal, perfect, fracture conchoidal or uneven H = 3 5, G = 4 748 Lead grey to iron black, sometimes iridescent, streak black, dull C c 25 4 copper, 49 antimony, and 25 6 sulphur Wolfsberg

218 **Berthierite**, FeS, SbS_3

Massive, columnar or fibrous, with indistinct cleavage H = 2 3, G = 4 to 4 3 Dark steel grey, reddish Tintagel and Padstow in Cornwall, Auvergne and Anglars (Creuse) in France, Braunsdorf in Saxony In France used as an ore of antimony

219 **Plagionite**, Pb_4Sb_3

Oblique prismatic, C 72° 28′ P 134° 30 and 142° 3, −2P 120° 49 Crystals thick, tabular (fig 350), minute, and in druses Cl −2P, perfect, brittle H = 2 5, G = 5 4 Blackish lead grey C c 41 lead, antimony, and 21 sulphur Wolfsberg

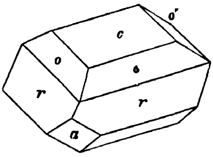


Fig 350 (sp 219)

220 **Klaprothite**, $3Cu\,S + 2Bi_2S_3$

Right prismatic, long striated crystals, ∞P = 107° Wittichen, Bulach *Schirmerite*, from Colorado, $3(Ag\,Pb)S + 2Bi_2S_3$ with G. = 6 74, is similar

221 **Binnite**, $3CuS + 2As\,S_3$

Cubic Typical forms ∞O 2O2 O, ∞O∞, 6O6, 4O4, 10O10 3O$\frac{3}{2}$ H = 4 5 G = 4 48 Metallic Black Binnen

222 **Jamesonite**, $3PbS + 2Sb_2S_3$

Right prismatic, ∞P 101° 20 Crystals ∞P, ∞P̆∞, long prismatic, parallel or radiating Cl basal perfect, ∞P and brachydiagonal imperfect, sectile H = 2 to 2 5, G = 5 5 to 5 7 Steel grey to dark lead grey B B decrepitates, fuses easily, and wholly volatilizes except a small slag Sol in warm n acid C c 44 5 lead, with 2 to 4 iron, 34 9 antimony, and 20 6 sulphur Cornwall, Estremadura, Hungary, Siberia, and Brazil

223 **Dufrenoysite**, $2PbS + As_2S_3$

Right prismatic ∞P 93° 39 Generally in thick rectangular tables H = 3, G = 5 56 Lead grey Brittle Binnen, St Gotthard

224 **Freieslebenite**, $5(Pb, Ag_2)S + 2Sb\,S_3$

Oblique prismatic, C 87° 46 ∞P 119° 12, P∞ 31° 41 (fig 351) in prisms with curved reed like faces, and strong vertical striæ Twins intersecting, also massive Cl ∞P, perfect, fracture conchoidal or uneven, rather brittle H = 2 to 2 5, G = 6 2 to 6 4 Steel grey to dark lead grey C c 22 5 silver, 32 4 lead, 26 8 antimony, and 18 3 sulphur Freiberg (Saxony), Hiendelaencina (Spain)

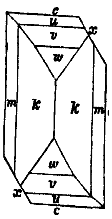


Fig 351 (sp 224)

225 **Pyrargyrite**, $3Ag_2S + Sb_2S_3$

Hexagonal rhombohedral, R (*P*) 108° 42′, −½R 137° 58, 0R, −2R (*r*), R3, ∞P2 (*s*), and ∞R (*l*) Crystals prismatic (fig 352), twins common, of various kinds, also massive, dendritic, or investing Cl R, rather perfect, fracture conchoidal to uneven and splintery sectile H = 2 to 2 5 Crimson red to blackish lead grey, streak cochineal to cherry red Huel Brothers and Huel Duchy in Cornwall, Andreasberg, Freiberg Johann Georgenstadt, Annaberg, Schneeberg, Marienberg, Przibram, Schemnitz and Kremnitz, Kongsberg, Mexico, Nevada, &c

226 **Proustite**, $3Ag_2S+As_2S_3$

Rhombohedral, like pyrargyrite, except R 107° 50′ (fig 353) G = 5 5 to 5 6 Semi-transparent to translucent on the edges Cochineal to crimson red C c 65 5 silver, 15 1 arsenic, and 19 4 sulphur Streak aurora red B B arsenical odour, and difficultly reduced to metallic silver At the same localities as pyrargyrite, both are valuable ores of silver Red orpiment has a lower specific gravity, and yellow streak, cinnabar volatilizes before the blowpipe

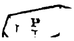


Fig 352 (sp 225)

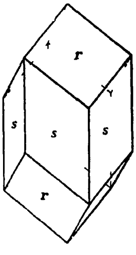


Fig 353 (sp 226)

227 **Boulangerite**, $3PbS+SbS_3$

Fine granular, columnar, radiating, or fibrous, slightly sectile H = 3, G = 5 8 to 6 Silky, metallic Blackish lead grey, with darker streak B B like jamesonite C c 59 lead, 22 8 antimony, and 18 2 sulphur Molieres in France, Oberlahr (Rhenish Prussia), Lapland, and Siberia *Plumbostib* or *Embrethite*, from Nertchinsk, is only a variety

228 **Kobellite**, $3PbS, Bi_2S_3+3PbS, Sb_2S_3$

Radiated columnar, soft G = 6 2 to 6 3 C c 53 lead, 20 bismuth, 10 antimony, and 17 sulphur Hvena in Nerike (Sweden)

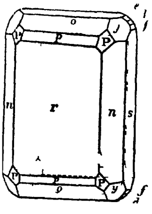
229 **Wittichenite** (*Cupreous Bismuth*), $3CuS+Bi_2S_3$

Right prismatic, in tabular crystals like bournonite Wittichen in the Black Forest

230 **Bournonite** $(3CuS+Sb_2S_3)+2(3PbS+Sb_2S_3)$

Right prismatic ∞P (*d*) 93° 40 $\breve{P}\infty$ (*n*) 96° 13, $\bar{P}\infty$ (*e*) 92° 34, 0P (*r*), $\infty\breve{P}\infty$ (*s*) $\infty\bar{P}\infty$ (*k*) (fig 354) Cl brachydiagonal, imperfect, fracture uneven to conchoidal, rather brittle H = 2 5 to 3, G = 5 7 to 5 9 Lustre brilliant metallic Steel grey C c 42 4 lead 13 copper, 25 antimony, and 19 6 sulphur Redruth and Beeralston, Harz (Neudorf) Braunsdorf, Kapnik, Servoz, Alais and Pontgibaud in France

Wolchite from Wolch in Carinthia is only a variety



ig 354 (sp 230)

231 **Aikinite** (*Needle ore*), $2(3PbS+Bi_2S_3)+3(CuS+Bi_2S_3)$

Right prismatic, long thin crystals imbedded in quartz, often bent or broken, rather brittle H = 2 5 G = 6 7 to 6 8 Blackish lead grey or steel grey, with a brownish tarnish C c 36 lead, 11 copper, 36 bismuth, and 17 sulphur Berezoff (Siberia), Georgia

232 **Stylotyp**, $3(CuAgFe)S+Sb_2S_3$

Right prismatic 0P 92° 30 H = 3 G = 4 8 Black Copiapo, Chili

233 **Annivite**, $4CuS+(As_2S_3, Sb_2S_3, Bi_2S_3)$

Massive, similar to the foregoing From Anniver in Valais *Studerite* is similar, but with 15 5 of antimony

234 **Julianite**, $3Cu_2S+As_2S_3$

Cubic G = 5 12 Metallic Reddish grey Rudelstadt in Silesia

235 **Meneghinite**, $4PbS+Sb_2S_3$

Oblique prismatic, C 72° 8′ ∞P 140° 24 $P^{\circ}\infty$ 70° Crystals small, acicular, chiefly of $\infty P^{c}\infty$, $\infty P^{\circ}\infty$, ∞P rare, mostly fibrous H = 3 G = 6 4 Bottino in Tuscany, Schwarzenberg in Saxony

236 **Jordanite**, $4PbS+As_2S_3$

Right prismatic, ∞P 123° 29 Cl brachydiagonal, perfect Streak black G = 6 38 C c lead 68 9, arsenic 12 5, sulphur 18 6 Binnen and Nagyag

237 **Tetrahedrite** (*Fahlerz*), $4Cu_2S+Sb_2S_3$.

Tesseral and tetrahedral In crystals $\frac{O}{2}$, $-\frac{O}{2}$, ∞O, $\frac{2O2}{2}$ (figs 355 to 358, also 65, 66, 206) Twins (figs 164, 207), generally massive Cl octahedral, fracture conchoidal, brittle H = 3 44, G = 4 5 to 5 2 Steel grey to iron-black, streak black (dark red when containing zinc) B B on charcoal boils slightly, and fuses to a steel grey slag, usually magnetic, and with soda gives copper C c essentially Cu_2S in combination with Sb_2S_3 Airthrey near Stirling, Sandlodge in Shetland, Tomnadashin on Loch Tay, Kirkcudbright, Crinnis and other Cornish mines near St Austell, Harz, Müsen, Freiberg Camsdorf, Alsace, Kremnitz and Kapnik Those with 17 to 31 silver are the *Silver Fahlore* (Freiberg) Ore of copper and silver

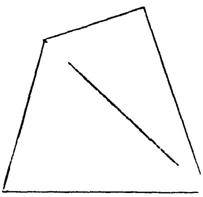


Fig 355

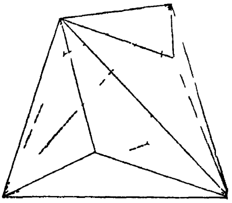


Fig 356

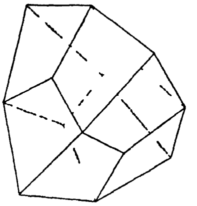


Fig 357

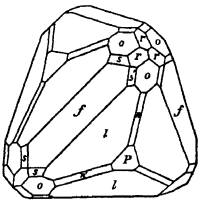


Fig 358

238 **Tennantite**, $(CuS, FeS)As_2S_3$

Cubic (like fig 237) Cl ∞O Brittle H = 4, G = 4 3 to 4 5 Iron black, streak dark red grey C c 49 copper, 4 iron, 19 arsenic, and 28 sulphur Redruth and St Day (Cornwall) and Skutterud *Copper blende*, with brownish red streak, G = 4 3, contains 8 9 zinc, Freiberg

239 **Polytelite** (*Weissgiltigerz*), $4RS+Sb_2S_3$

Like tetrahedrite H = 2 5, G = 5 4 to 5 7 C c silver 6 to 22, lead 38 to 52, antimony 8 5 to 22, sulphur 13 to 22 5 Freiberg

240 **Stephanite**, $5Ag_2S+Sb_2S_3$

Right prismatic ∞P (*o*) 115° 39, P (*P*) middle edge 104° 20, $2\breve{P}\infty$ (*d*) middle edge 107° 48 0P (*s*), $\infty\breve{P}\infty$ (*p*) (figs 333, 334) Cl *d* and *p*, both imperfect, fracture conchoidal or uneven sectile H = 2 to 2 5, G = 6 2 to 6 3 Iron black to blackish lead grey C c 68 5 silver, 15 3 antimony, and 16 2 sulphur Cornwall, Freiberg, Schneeberg, Annaberg, Joachimsthal, Przibram, Schemnitz, Mexico, Peru, and Siberia Valuable ore of silver

241 **Geocronite**, $5PbS+(Sb, As)_2S_3$

Right prismatic Fracture conchoidal, sectile H = 2 to 3 G = 6 45 to 6 54 Pale lead grey C c 67 lead, with 1 to 2 copper and iron, 16 antimony, with 4 7 arsenic and 17 sulphur Sala in Sweden, Meredo (Oviedo) in Spain, and near Pietrosanto in Tuscany

242 **Kilbrickenite**, $6PbS+Sb_2S_3$

Massive, granular or foliated C c 70 01 lead, 13 76 antimony, and 16 23 sulphur County Clare in Ireland

243 **Polybasite**, $9(Ag, Cu)S+(Sb, As)_2S_3$

Hexagonal, P 117° Crystals 0P ∞P and 0P, P, tabular. Cl basal, imperfect, sectile, and easily frangible H = 2 to 2 5, G = 6 to 6 25 Iron black, in very thin lamellæ, translucent, red C c 64 to 72 silver, 3 to 10 copper, 16 to 17 sulphur, 0 2 to 8 antimony, and 1 to 6 arsenic Freiberg, Joachimsthal, Schemnitz, Guanajuato, Nevada and Idaho Rich ore of silver

244 **Polyargyrite**, $12AgS+Sb_2S_3$

Cubic Typical form O, $\infty O\infty$, ∞O, mOn Cl cubic H = 2 5, G = 6 97 Metallic, iron black streak black Malleable C c 78 2 silver, 7 4 antimony, 14 5 sulphur Wolfach in Baden

245 **Enargite**, $3Cu_2S+As_2S_5$

Right prismatic Cl ∞P 97° 53 perfect, brachydiagonal 100° 58 and macrodiagonal less so Typical form ∞P 0P, $\infty\bar{P}\infty$, $\infty\breve{P}\infty$. Brittle H = 3, G = 4 3 to 4 5 Iron black C c 48 3 copper, 19 1 arsenic, and 32 6 sulphur Morococha in Peru

246 **Clarite**, $3CuS+AsS$

Oblique prismatic Cl clinodiagonal Ordinary form ∞P, ∞P̀∞ 0P *m*P H = 3.5 G = 4.46 Dark bluish grey Kinzigthal in Baden *Luzonite* is similar

247 **Famatinite**, $3CuS+SbS$

Right prismatic Typical form 0P, ∞P, ∞P̄∞, ∞P̆3 Massive or reniform H 3.5 G 4.57 Copper red to grey streak black Famatina Mts in the Argentine Republic, and Cerro de Pasco in Peru

248 **Chiviatite**, $2PbS+3Bi_2S_3$

Foliated, massive G = 6.9 Metallic Lead grey Chiviato in Peru

249 **Epigenite**, $6RS+AsS_5$

Right prismatic ∞P 110° 50 Steel grey H = 3.5 Wittichen

250 **Thiboulangerite** $3PbS+Sb_2S_5$

Right prismatic G = 6.3 Metallic Blue black Altenburg in Silesia

251 **Xanthocon**, $2(3Ag_2S+As_2S_3)+(3Ag_2S+As_2S_5)$

Hexagonal rhombohedral R 0R 110° 30 Crystals thin hexagonal tables little easily frangible H = 2 to 2.5, G = 5 to 5.2 Translucent adamantine Orange yellow or brown streak darker In the closed tube fuses easily becomes lead grey C c 63.4 silver, 14.7 arsenic, and 21.9 sulphur Himmelsfurst mine at Freiberg

252 **Pyrostilpnite** (*Fire blende*)

Oblique prismatic crystals like stilbite 0P 139° 12 Twins on orthodiagonal H = 2 G = 4.2 Lustre pearly, and adamantine Colour hyacinth red and bright yellow Sectile C c 62.3 silver, with sulphur and antimony Freiberg Andreasberg, Przibram

OXYSULPHURETS.

253 **Kermesite**, SbO_3+2SbS_3

Oblique prismatic crystals ∞P̄∞ 0P acicular and diverging sectile H = 1 to 1.5, G = 4.5 to 4.6 Translucent, adamantine Cherry red streak similar Sol in h acid In potash solution becomes yellow, and dissolves C c 75.3 antimony 19.8 sulphur 4.9 oxygen Braunsdorf Przibram, Pernek near Bosing (Hungary), Allemont, Southham (Canada)

254 **Voltzine**, $ZnO+4ZnS$

Incrusting H = 4.5 G = 3.7 Yellow Pontgibaud and Joachimsthal

255 **Karelinite**, $3BiO+BiS$

H = 2 G = 6.6 Metallic Lead grey Zavodinski in the Altai

256 **Bolivite**, $Bi_2O_3+Bi_2S_3$

Rhombohedral From Bolivia

SELENITES

257 **Chalcomenite** $CuSe+2H$ [$=CuO, SeO_2+2H_2O$]

Oblique prismatic C 108 20 G = 3.76 Bright blue Transparent C c selenious acid 48.2 copper oxide 35.4, water 15.3 Cerro de Cacheuta (Mendoza Argentine Republic)

NITRATES AND BORATES

258 **Nitratine**, Na_2N [$=Na_2O\ N_2O_5$]

Rhombohedral R 106° 30 Tarapaca in Peru Used in the arts as a substitute for nitre, but deliquesces in moist air

259 **Nitre** (*Saltpetre*), KN [$=K_2O\ N_2O_5$]

Right prismatic ∞P (*M*) 118° 49, 2P̆∞ (*P*) 70° 55, P̆∞ 109° 52 ∞P̆∞(*h*) (fig 275) isomorphous with aragonite Acicular, capillary, or pulverulent Cl indistinct fracture conchoidal H = 2, G = 1.9 to 2 Semitransparent vitreous or silky Colourless, white or grey Taste saline and cooling Deflagrates when placed on hot charcoal and B B on platina wire melts very easily, colouring the flame violet C c 46.6 potash and 53.4 nitric acid, but always more or less impure In the limestone caves of many countries, Hungary Spain India Used for producing nitric acid, in glass making, medicine and the manufacture of gunpowder

260 **Nitrocalcite**, CaN_2+H

Fibrous or pulverulent White or grey C c 30.8 lime, 59.3 nitric acid, and 9.9 water Limestone caves of Kentucky, on old walls and limestone rocks

261 **Nitromagnesite**, $MgN+H$

Taste bitter In the same places, and similar to nitrocalcite

262 **Boracite**, $2Mg_3B_4+MgCl$

Tesseral and hemihedral (figs 63, 253, 359) Cl octahedral, imperfect, fracture conchoidal, brittle H = 7, G = 2.9 to 3 Transparent or translucent, vitreous or adamantine Colourless or white, often greyish, yellowish, or greenish Becomes polar electric by heat B B fuses with difficulty to a clear yellowish bead, which on cooling forms a white opaque mass of needle like crystals, at the same time colours the flame green Sol in h acid C c 62.5 boracic acid, 26.9 magnesia, 7.9 chlorine, and 2.7 magnesium Luneberg, Segeberg in Holstein, Stassfurt

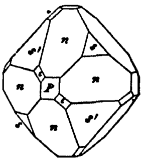


Fig 359

263 **Stassfurtite**

In very minute prismatic crystals White C c same as boracite, and thus perhaps dimorphous Stassfurt

264 **Rhodizite**, $2Ca_3B_4$ (?)

H = 8 and G = 3.3 to 3.42, agrees in most characters with boracite Pyro electric Mursinsk in Siberia

265 **Ludwigite**, $2MgB+FeFe_2$

Fibrous masses From limestone at Morawitza in the Banat

266 **Borax** (*Tinkal*) $Na_22B+10H_2$

Oblique prismatic, C 73° 25 ∞P 87°, P 122° 34 (fig 360) Almost isomorphous with augite, brittle H = 2 to 2.5, G = 1.7 to 1.8 Pellucid, resinous Colourless, or yellowish greenish, and greyish white Taste feebly alkaline and sweetish C c 16.4 soda, 36.5 boracic acid and 47.1 water, but often with 2 phosphoric acid or other impurities Shores of salt lakes in Tibet and Nepal, in California, and near Potosi

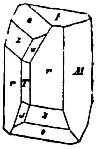


Fig 360 (sp 266)

267 **Borocalcite**, $Ca2B+6H$

Similar to ulexite (sp 268), and from same locality

268 **Ulexite**, $Na2B+2Ca2B+18H$

Fibrous H = 1 G = 1.6 White Tasteless Iquique and Nova Scotia

269 **Szaibelyite** $2Mg_52B+3H_2$

H = 3.5, G = 2.7 Werksthal in Hungary

270 **Hydroboracite**, $2Ca3B_3+2Mg3B_3+12H_2$

Radiating and foliated Caucasus A similar mineral, with soda in place of magnesia, is found in Peru

271 **Sussexite**, $(Mn, Mg)_2B+H_2$

Fibrous, silky White H = 3, G = 3.4 Franklin (Sussex county, New Jersey)

ANHYDROUS CARBONATES

272 **Calcite** (*Calc spar, Calcareous Spar*), CaC

Hexagonal and rhombohedral, R 105° 5 (fig 101) The forms and combinations exceed those of any other mineral Among them are more than fifty rhombohedrons, especially −½R 135°, R, −2R 79°, and 4R 66°, with 0R and ∞R as limiting forms There are one hundred and fifty five distinct scalenohedrons, as R3, R2 ¼R3, and the second hexagonal prism ∞P2 Hexagonal pyramids are among the rarer forms Some of the most usual combinations are ∞R −½R (*c*, *g*, fig 179), or −½R ∞R, very frequent, also ∞R, 0R, likewise −2R, R (*f*, *P*, fig 107), R3, ∞R, −2R, R5 (*y*), R3 (*r*), R (*P*), 4R (*m*), ∞R (*c*) (fig 109), R, R3 (fig 108) Several hundred distinct combinations are known

Hemitropes and twins are not uncommon These occur with the axes parallel (figs 106, 146, 148, 180, 366, 367) Others are conjoined by a face of R the axes being almost at right angles, 89° 8 (figs 183, 369) or by a face of −½R, in which the chief axes form an angle of 127½°, and usually many times repeated, so that the centre crystals appear in lamellæ not thicker than paper (fig 181), at an obtuse angle, as figs 149, 363, or an acute

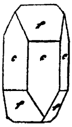


Fig 361

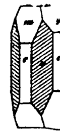


Fig 362

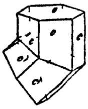


Fig 363

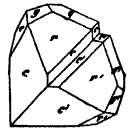


Fig 364

angle, as figs 364 368 Also occurs granular, lamellar parallel or radiated fibrous, compact and earthy Cl rhombohedral along R, very perfect and easily obtained, so that the conchoidal fracture is rarely observable, brittle H = 3, G = 2 6 to 2 8, pure transparent crystals = 2 72 Pellucid in all degrees Very distinct double refraction Lustre vitreous but several faces resinous and 0R pearly Most frequently colourless or white, but often grey, blue, green, yellow, red, brown, or black, streak greyish white B B infusible, but becomes caustic and emits a bright light Effervesces, and is entirely sol in h or n acid The fine powder, ignited on platina foil over the spirit lamp, forms a somewhat connected mass, and even adheres to the platina C c of the purest varieties, carbonate of lime with 44 carbonic acid and 56 lime, but usually contains magnesia and protoxide of iron or of manganese Remarkable specimens of the crystallized variety or proper calc spar are found at Alston Moor in Cumberland (flat rhombic crystals) and in Derbyshire (pale yellow transparent pyramids) at Strontian Elie in Fife (figs 370, 371, 372), Andreasberg and other parts of the Harz (six sided prisms) and at Freiberg, Tharand and Maxen in Saxony

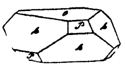


Fig 365

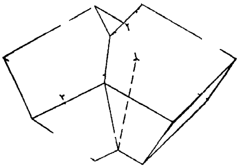


Fig 366

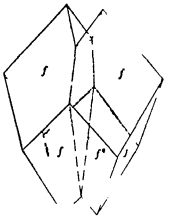


Fig 367

Certain varieties are distinguished *Iceland Spar* remarkable for its transparency and double refraction occurs massive and in huge crystals in a trap rock in Iceland *Slate Spar* thin lamellar, often with a shining white pearly lustre and greasy feel Abergairn and Glen Tilt in Scotland Wicklow in Ireland, and Norway *Aphrite*, fine scaly, from Hesse and Thuringia *Marble* is the massive crystalline variety of this mineral produced by igneous action on compact limestone Paros, Naxos, and Tenedos furnished the chief supply to the Grecian artists, Carrara near the Gulf of Genoa to those of modern times Some of the coloured marbles of the ancients were impure limestones, as the *Cipollino*, zoned with green talc or chlorite, and *Verde Antique*, mixed with green serpentine *Ruin Marble* shows irregular markings like ruins, Val d Arno (Florentine marble), and Bristol (Cotham marble) *Lucullite* from Egypt, and *Anthraconite*, from Campbelltown and Kilkenny, are black from carbon *Lumachello*, from Bleiberg in Carinthia exhibits beautiful iridescent colours from fossil shells sometimes deep red or orange (*Fire Marble*) *Hislopite* from Poonah, is green from celadonite

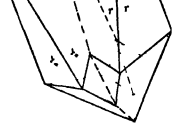


Fig 368

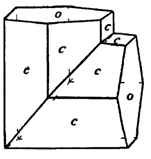


Fig 369

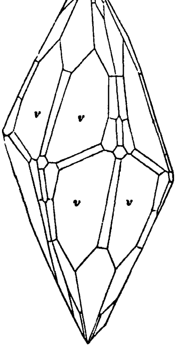


Fig 370

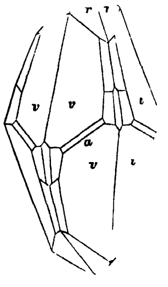


Fig 371

Limestone occurs in all formations under various names, as *Oolite*, egg stone, or roe stone —round concretions with a concentric structure like the roe of a fish *Pisolite*, or peastone similar structure *Chalk*, soft earthy *Lithographic Stone* yellowish and compact, from Solenhofen, and *Marl*, calcareous matter more or less mixed with clay *Calcareous Tufa*, generally a recent deposit from calcareous springs, has often a loose friable texture, but at other times is hard and compact, and in the neighbourhood of Rome forms the common building stone *Travertino* The sandstone of Fontainebleau is carbonate of lime (⅓) mixed with quartz sand (⅔), and occasionally crystallizing in rhombohedrons

This mineral is employed in many ways —the coarser varieties when burnt to drive off the carbonic acid as lime for mortar manure tanning, as a flux in melting iron and other ores, or in preparing glass and for similar purposes the finer, as marbles for sculpture architec and ornamental stone work the chalk for writing, white washing, or producing carbonic acid

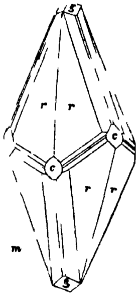


Fig 372

Plumbocalcite —Cl 104° 53 White and pearly, softer than calc spar but G = 2 824 Contains 2 3 to 7 8 carbonate of lead Wanlockhead and Leadhills (Scotland)

273 DOLOMITE (*Bitter spar*) $CaC + MgC$

Hexagonal rhombohedral R 106° 1 20 most frequent form R The rhombohedrons often curved and saddle shaped also granular or compact often cellular and porous Cl rhombohedral H = 3 5 to 4 5 G = 2 85 to 2 95 Translucent vitreous but often pearly Colourless or white but frequently pale red yellow, or green B B infusible but becomes caustic and often shows traces of iron and manganese Fragments effervesce very slightly or not at all in hydrochloric acid the powder is partially soluble, or wholly when heated C c 54 3 carbonate of lime and 45 7 carbonate of magnesia but generally carbonate of lime with more than 20 per cent carbonate of magnesia and less than 20 per cent carbonate of iron

Varieties are—*Dolomite* massive granular, easily divisible white, *Rhomb* or *Bitter-spar*, larger grained or distinctly crystallized and cleavable often inclining to green and *Brown spar* and *Pearl spar*, in simple crystals generally curved (fig 231) or in imitative forms, of colours inclining to red or brown more distinct pearly lustre, and under 10 per cent carbonate of iron Leadhills and Charlestown in Scotland, Alston in Cumberland, in Derbyshire, Traversella in Piedmont, St Gotthard Gap in France Greenish, twinned Miemo in Tuscany (*Miemite*) and Tharand in Saxony (*Tharandite*)

The massive and compact varieties are very common and are valued as building stones (cathedral of Milan York Minster, and the Houses of Parliament at Westminster) The Parian marble, and also the Sutherland and Iona marbles, belong to this species

274 ANKERITE, $CaC + (MgFe)C$

R 106° 12 Usually massive and granular G = 2 9 to 3 1. Otherwise like siderite Unst (Shetland), Styria

275 MAGNESITE, MgC

Rhombohedral, 107° 10 –30 Reniform or massive H = 3 5, G = 2 85 to 2 95 Subtranslucent or opaque, streak shining Snow white, greyish or yellowish white, and pale yellow Tyrol, Norway, North America

276 BREUNNERITE (*Giobertite*), $MgC + (MnFe)C$

Hexagonal rhombohedral R 107° 10 –30 Granular or columnar Cl R, very perfect H = 4 to 4 5, G = 2 9 to 3 1 Transparent or translucent on the edges, highly vitreous Colourless but often yellowish brown or blackish grey C c essentially carbonate of magnesia, with 51 7 carbonic acid and 48 3 magnesia, but often mixed with 8 to 17 carbonate of iron or manganese Unst, Tyrol (in Fassa Valley, &c), St Gotthard, Harz.

277 SIDERITE (*Sparry Iron, Chalybite*), FeC

Hexagonal and rhombohedral R 107° Chiefly R often curved, saddle shaped (fig 232), or lenticular Cl rhombohedral along R, perfect, brittle H = 3 5 to 4 5 G = 3 7 to 3 9 Translucent in various degrees, becoming opaque when weathered vitreous or pearly Rarely white, generally yellowish grey or yellowish brown changing to red or blackish brown on exposure B B infusible, but becomes black and magnetic with borax and salt of phosphorus shows reaction for iron, with soda often for manganese In acids soluble with effervescence C c carbonate of iron, with 62 1 protoxide of iron and 37 9 carbonic acid but usually 0 5 to 10 or even 25 protoxide of manganese, 0 2 to 15 magnesia, and 0 1 to 2 lime Unst Kintyr In beds or masses in Beeralston in Devonshire, Alston Moor in Cumberland, and in many of the tin mines in Cornwall in Styria Carinthia, and Westphalia, in veins in Anhalt and the Harz also in the Pyrenees and the Basque provinces of Spain as near Bilboa in crystals at Joachimsthal, Freiberg, Klausthal

Clay Ironstone grey, blue brown, or black —G = 2 8 to 3 5, H = 3 5 to 4 5 —is an impure variety

278 DIALOGITE (*Red Manganese*) MnC

Hexagonal rhombohedral R 106° 56 Crystals often curved, lenticular or saddle shaped also spherical, reniform, and columnar or granular Cl R perfect H = 3 5 to 4 5 G = 3 3 to 3 6 Translucent vitreous or pearly Rose red to flesh red, streak white C c 62 manganese protoxide and 38 carbonic acid Freiberg, Schemnitz, Kapnik Nagyag Elbingerode, and near Sargans

279 COBALTSPATH CoC

Rhombohedral and spheroidal H = 4, G = 4 to 4 13 Peach blossom red but dark externally Schneeberg

280 SMITHSONITE (*Calamine*) ZnC

Hexagonal rhombohedral R 107° 40 Usually reniform, stalactitic and laminar or granular Cl R, perfect but curved, fracture uneven conchoidal brittle H = 5 G = 4 1 to 4 5 Translucent or opaque, pearly or vitreous Colourless but often pale greyish yellow brown or green C c 64 8 zinc oxide and 35 2 carbonic acid Mendip in Somersetshire, Matlock in Derbyshire compact at Alston Moor Chessy near Lyons Altenberg near Aix la Chapelle, Brilon in Westphalia Tarnowitz in Silesia Hurgau, Siberia

281 ARAGONITE, CaC

Right prismatic ∞P 116° 10, P̆∞ 108° 26 The most common combinations are ∞P̆∞ (*h*) ∞P̆ (*M*), P∞ (*k*, *P*) (fig 275), generally long prismatic (like the separate crystals in fig 184), ∞P̆∞, ∞P, 0P, generally short prismatic crystals of 6P̆$\frac{3}{2}$, ∞P, P̆∞, 6P̆∞ (*q*) (fig 373) acute pyramidal But simple crystals are rare, from the great tendency to form twins, conjoined by a face of ∞P and repeated either in linear arrangement (fig 185) or in rosette grouping (fig 186) Also columnar fibrous and in crusts stalactites, and other forms Cl brachydiagonal distinct fracture conchoidal or uneven H = 3 5 to 4 G = 2 9 to 3 (massive 2 7) Transparent or translucent, vitreous Colourless, but yellowish white to brick red also light green violet blue or grey In the closed tube, before reaching a red heat it swells and falls down into a white coarse powder, evolving a little water Unst and Leadhills Valencia Molina and elsewhere in Aragon Leogang in Salzburg and Antiparos *Flos ferri* coralloid in the iron mines of Styria. *Satin spar* fine fibrous silky at Dufton (Westmoreland) Stalactitic coast of Galloway Leadhills, Buckinghamshire and Devonshire Also deposited as tufa by the Carlsbad and other hot springs

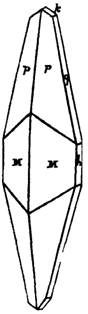


Fig 373.

282 WITHERITE, BaC

Right prismatic ∞P (*g*) 118° 30 2P̆∞ (*I*) 112° Crystals not common like fig 275 but generally with quite an hexagonal aspect from being twinned like aragonite (fig 374) Oftener spherical botryoidal or reniform with radiated columnar structure Cl ∞P distinct fracture uneven H 3 to 3 5 G = 4 2 to 4 3 Semitransparent or translucent vitreous or resinous on the fracture Colourless but generally yellowish or greyish B B fuses easily to a transparent globule opaque when cold, on charcoal boils becomes caustic and sinks into the support soluble with effervescence in n or h acid C c 22 carbonic acid and 77 7 baryta Alston Moor and Hexham in Northumberland also in Styria, Salzburg, Hungary, Sicily Siberia, and Chili

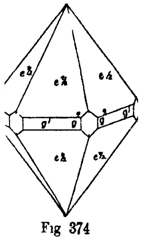


Fig 374

283 ALSTONITE, BaC + CaC

Right prismatic ∞P 118° 50 2P̆∞ 111° 50 usual combination P, 2P∞, ∞P resembling an hexagonal pyramid (fig 375) Cl ∞P and ∞P̆∞, rather distinct H = 4 to 4 5; G = 3 65 to 3·76. 3 76 Translucent, weak resinous Colourless or greyish white C 66 carbonate of baryta and 34 carbonate of lime Fallowfield near Hexham, and Alston Moor

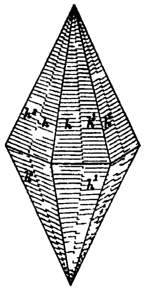


Fig 375 (sp 283)

284 STRONTIANITE, SrC.

Right prismatic ∞P 117° 19, P̆∞ 108° 12 Crystals (fig 376) and twins like aragonite, also broad columnar and fibrous Cl prismatic along ∞P (*M*) H = 3 5, G = 3 6 to 3 8 Translucent or transparent, vitreous or resinous on fracture Colourless, but often light asparagus or apple green, more rarely greyish, yellowish, or brownish B B fuses in a strong heat only on very thin edges, intumesces in cauliflower like forms, shines brightly, and colours the flame red, easily soluble in acids, with effervescence C c 30 carbonic acid and 70 strontia but often contains carbonate of lime (6 to 8) Strontian in Argyllshire, Sutherland, Leogang in Salzburg, Braunsdorf in Saxony, Hamm in Westphalia, the Harz, at Schoharie (N Y) and elsewhere in United States (*Emmonite*) It is used to produce red fire in pyrotechnic exhibitions

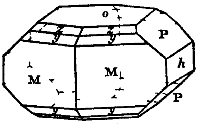


Fig 376

285 MANGANOCALCITE, (Mn, Ca, Fe) C

Right prismatic, in prisms like aragonite, and bears the same relation to dialogite that aragonite does to calc spar H = 4 to 5, G = 3 03 Red or reddish white Vitreous Schemnitz

286 CERUSSITE (*Lead Spar*), PbC

Right prismatic isomorphous with aragonite and nitre ∞P (*M*) 117° 14, P̆∞ 108° 16, 2P̆∞ (*u*) 69° 20, also 0P, P (*t*) $\frac{1}{2}$P̆∞ (*s*), ∞P̆∞ (*l*), ∞P̆3 (*e*) (fig 377) Twins common (figs 158, 159 378, 379) Also granular or earthy Cl ∞P and 2P̆∞, rather distinct fracture conchoidal easily frangible H = 3 to 3 5, G = 6 4 to 6 6 Transparent or translucent, adamantine or resinous Colourless and often white, but also grey, yellow, brown, black rarely green, blue, or red streak white B B decrepitates violently, but easily fused and reduced, soluble with effervescence in n acid C c 83 5 protoxide of lead and 16 5 carbonic acid Very common Leadhills, Wanlockhead, Keswick, Alston Moor, Beeralston in Devonshire, St Minver in Cornwall, Przibram, Mies, and Bleistadt; Tarnowitz, Johann Georgenstadt, Zellerfeld, Klausthal, and many other places

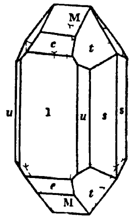


Fig 377

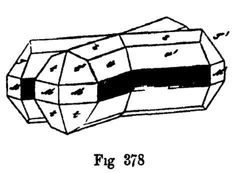


Fig 378

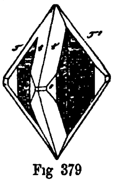


Fig 379

287 BARYTO CALCITE, BaC + CaC.

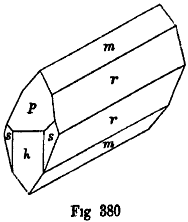


Fig 380
Oblique prismatic, C 69°

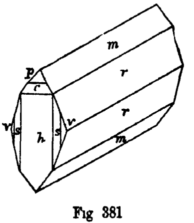


Fig 381
∞P (*m*) 84° 52′, P (*s*) 106° 54′,

P°∞ (*h*) 61° (figs 380, 381), also columnar and granular Cl P perfect, P°∞ less perfect. H = 4, G = 3 6 to 3 7 Transparent or translucent, vitreous, inclining to resinous Yellowish white C c like alstonite Alston Moor

288 **Bismuto sphærite**, Bi_2C

Small fibrous brown concretions from Neustadtel, near Schneeberg

HYDROUS CARBONATES

289 **Thermonatrite**, $Na_2C + H$

Right prismatic ∞P̆2 (*d*) 107° 50′, P̆∞ (*o*) 83° 50, with ∞P̆∞ (*P*) in rectangular tables (fig 382) Cl brachydiagonal, perfect H = 1 5, G = 1 5 to 1 6 Colourless B B like natron, but does not melt C c 50 1 soda, 35 4 carbonic acid, and 14 5 water Nation lakes of Lagunilla in Venezuela, of Lower Egypt, and of the steppes between Urals and Altai

290 **Natron**, $Na_2C + 10H_2$.

Oblique prismatic, C 57° 40 Crystals artificial, with ∞P 79° 41, P 76° 28 Cl orthodiagonal, distinct H = 1 to 1 5 G = 1 4 to 1 5 Pellucid, vitreous Colourless or greyish white B B melts easily, colouring the flame yellow C c 22 soda 15 carbonic acid, and 63 water, but mixed with chloride of sodium and other salts Only as an efflorescence on the ground or rocks (lava of Vesuvius and Etna) in various countries (Hungary, Egypt Tartary), and in mineral springs and lakes Used in the manufacture of soap, in dyeing, and in bleaching

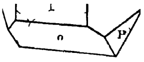


Fig 382 (sp 289)

291 **Trona, Urao**, $NaC_3 + 4H_2$

Oblique prismatic Crystals 0P (*T*), ∞P°∞ (*M*) P (*n*) *T M* 103° 15 (fig 383) Cl orthodiagonal, perfect H = 2 5 to 3, G = 2 1 to 2 2 Transparent to translucent Colourless Does not decompose in the air Taste alkaline C c 38 soda, 40 carbonic acid, and 22 water Fezzan and Barbary (*Trona*), Lagunilla (*Urao*)

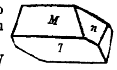


Fig 383

292 **Gaylussite**, $Na_2C + CaC + 5H_2$

Oblique prismatic, C 78° 27 Cl ∞P, imperfect, fracture conchoidal H = 2 5, G = 1 9 to 1 95. Transparent, vitreous Colourless C c 34 5 carbonate of soda, 33 6 carbonate of lime, 30 4 water, with 1 5 clay Lagunilla

293 **Hydromagnesite**, $Mg_4C_3 + 4H_2$

Oblique prismatic ∞P 88° nearly Crystals small, rare, also massive H = 1 5 to 3, G = 2 14 to 2 18 Vitreous or silky White C c 36 2 carbonic acid, 44 magnesia, and 19 8 water Unst (Shetland), Moravia, Kumi in Negropont, Hoboken in New Jersey, and Texas in Pennsylvania

294 **Azurite** (*Blue Copper*), $Cu_3C_2 + H_2$

Oblique prismatic, C 87° 39 ∞P (*M*) 99° 32, −P (*k*) 106° 14 Crystals 0P, ∞P, ∞P°∞, −P (or *h*, *M*, *s*, *k*, in fig 384, but in another position), also radiated and earthy Cl clinodomatic (*P*) 59° 14, rather perfect fracture conchoidal or splintery H = 3 5 to 4 2, G = 3 7 to 3 8 Translucent or opaque, vitreous Azure blue, the earthy varieties (and streak) smalt blue B B on charcoal fuses and yields a grain of copper, soluble with effervescence in acids, and also in ammonia. C c 69 1 protoxide of copper, 25 7 carbonic acid, and 5 2 water Crystals at Redruth, Alston Moor, Chessy near Lyons, in Siberia, Moldawa in the Banat, Burra Burra (Australia) Valued as an ore of copper

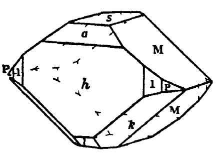


Fig 384

295 **Malachite**, $\dot{C}u_2C + H_2$.

Oblique prismatic, C 61° 50′ ∞P 104° 20 Crystals ∞P (*M*), ∞P°∞ (*s*), 0P (*P*), in hemitropes (fig 385) In general acicular, scaly, or reniform, stalactitic, and radiated fibrous Cl basal and clinodiagonal, very perfect H = 3 5 to 4, G = 3 6 to 4 Transparent or translucent on the edges, adamantine, vitreous, silky, or dull Emerald and other shades of green, streak apple green B B and with acids like azurite C c 71 8 copper protoxide (= 57 5 copper), 20 carbonic acid, and 8 2 water Crystalline at Rheinbreitenbach on the Rhine and Zellerfeld in the Harz, fibrous and compact at Sandlodge in Shetland, Leadhills, Cornwall, Wales and Ireland, at Chessy in France, Siberia, the Urals, Saalfeld in Thuringia, Moldawa in the Banat, in North America, Africa and Australia Frequently pseudomorphous after copper and its ores, also after calcite and cerussite Valuable ore of copper, the finer varieties are prized for ornamental purposes

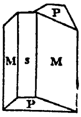


Fig 385

296 **Hydrozincite**, $ZnC + 2ZnH_2$

Massive C c zinc oxide 75 3, carbonic acid 13 6, water 11 1. Spain, Westphalia, Bavaria, Persia, United States Valuable ore

297 **Aurichalcite**, $2CuC + 3ZnH_2$

Acicular H = 2 Translucent, pearly, and verdigris green. C c 29 2 copper protoxide, 44 7 zinc oxide, 16 2 carbonic acid, and 9 9 water Leadhills, Matlock, Loktevski in the Altai

298 **Emerald Nickel** (*Zaratite*), $NiC + 6H_2$

Amorphous, reniform, and incrusting H = 3 G = 2 6 to 2 7. Translucent, vitreous Emerald green C c 59 3 nickel protoxide, 11 7 carbonic acid, and 29 water On chromite at Hagdale in Unst, Texas in Pennsylvania, also Cape Ortegal in Spain, Tyrol, and Ekaterinburg in the Urals

299 **Lindakerite**, $U_2C + 2CaC + 10H_2$

In small siskin green crystalline aggregates H = 2 5 to 3. From Elias mine near Joachimsthal, implanted on pitch blende

300 **Voglite**, $4UC + 7CaC + 3CuC + 24H_2$

Rhomboidal Emerald green scales with pearly lustre Elias mine, Joachimsthal

301 **Liebigite**, $U_2C + CaC + 20H_2$

Mammillary concretions H = 2 to 2 5 Apple green Adrianople, Joachimsthal, and Johann Georgenstadt

302 **Bismuthite** $Bi_4C_3 + 4H_2$

Disseminated, investing or acicular, fracture conchoidal or uneven, very brittle H = 4 to 4 5, G = 6 8 to 6 91 Opaque, dull vitreous Grey, yellow, or green C c 90 1 bismuth oxide, 6 4 carbonic acid and 3 5 water Ullersreuth (Reuss), Schneeberg, Johann Georgenstadt, also Chesterfield in South Carolina

3 **Lanthanite**, $LaC + 3H$

Right prismatic ∞P 92° 46 Small tabular crystals, usually granular or earthy Cl basal H = 2 G = 2 7 Dull or pearly White or yellowish C c 21 carbonic acid 55 lanthanum oxide, and 24 water Bastnaes in Sweden, Lehigh in Pennsylvania

CARBONATES WITH HALOID SALTS, &c

304 **Phosgenite**, $PbCl + PbC$

Pyramidal P 113° 56 Crystals short prismatic or sharp-pyramidal Cl ∞P, rather perfect, fracture conchoidal H = 2 5 to 3, G = 6 to 6 2 Transparent or translucent, resinous adamantine White, yellow, green, or grey C c 51 chloride and 49 carbonate of lead Very rare Stottfield near Elgin Scotland, Matlock and Cromford in Derbyshire, Tarnowitz

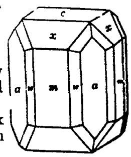


Fig 386

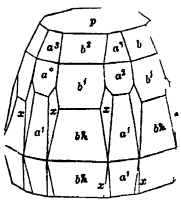


Fig 387 (sp 305)

305 **Parisite**, $3CeC + CaF$

Hexagonal P 164° 58 Cl basal, perfect H = 4 5, G = 4 35 Vitreous, on cleavage-plane pearly. Brownish yellow, inclining to red. C c 23 5 carbonic acid, 42 5 protoxide of cerium, 8 2 lanthanum oxide, 9 6 didymium oxide, 2 8 lime, 10 1 fluoride of calcium, and 2 2 fluoride of cerium Emerald mines of the Muzo Valley in Colombia, Urals.

306 **Leadhillite** (*Maxite*), $Pb_{18}C_9S_5O_{51} + 5H_2$

Right prismatic P middle edge 137°, ∞P 120° 20′, 2P̆∞ 43° 12′.

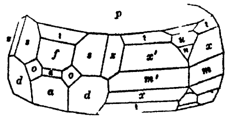


Fig 388

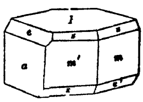


Fig 389

Mostly tabular, also twins Cl basal, perfect, slightly brittle. H = 2 5, G = 6 26 to 6 44 Transparent or translucent, resinous or adamantine, pearly on 0P Yellowish white, inclining to grey, green, yellow or brown C c 81 98 oxide of lead, 8 03 carbonic acid, 8 12 sulphuric acid, 1 8 water Leadhills Taunton Nertchinsk, Granada *Maxite* from Sardinia

307 SUSANNITE $3PbC + PbS$

Rhombohedral, R 72° 29 Cl basal perfect H = 2 5 G = 6 55 White green yellow brownish Resinous to adamantine pearly on the cleavage faces Powder white C c 72 5 carbonate and 27 5 sulphate of lead From the Susanna mine at Leadhills but very rare also in large dark crystals from the Banat

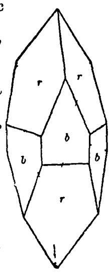


Fig 390 (sp 307)

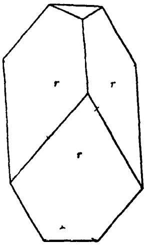


Fig 391 (sp 307)

ANHYDROUS SULPHATES

308 ARCANITE (*Glaserite*) KS

Right prismatic Acute pyramids, with ∞P 120° 24, dimorphous and also rhombohedral with R 88° 14 Mostly in crusts or pulverulent Cl basal imperfect H = 2 5 to 3, G = 2 7 Pellucid vitreous or resinous Colourless or white C c 54 potash and 46 sulphuric acid Lavas of Vesuvius and other volcanoes

309 MASCAGNINE $(NH_4)S$

Right prismatic ∞P 121° 8 but chiefly in crusts and stalactites Cl perfect sectile H = 2 to 2 5, G = 1 7 to 1 8 Pellucid, vitreous Colourless white, or yellowish Taste pungent and bitter C c 25 9 ammonia 60 5 sulphuric acid and 13 6 water Near volcanoes, as Etna, Vesuvius, the Solfatara the Lipari Islands in the marshes near Siena and in ignited coal beds, as at Bradley in Staffordshire

310 THENARDITE NaS

Right prismatic Acute pyramids P, with 0P and ∞P in crusts and druses Cl basal perfect fracture uneven H = 2 5 G = 2 6 to 2 7 Pellucid, vitreous White C c 43 82 soda and 56 18 sulphuric acid In salt deposits near Aranjuez (Spain) and at Tarapaca (Peru)

311 GLAUBERITE (*Brongniartine*) $NaS + CaS$

Oblique prismatic C 68° 16 0P − P or with ∞P (*P, f M* fig 392) Cl basal, perfect, along ∞P traces H = 2 5 to 3 G = 2 75 to 2 85 Translucent, vitreous to resinous Colourless C c 51 sulphate of soda, and 49 sulphate of lime Villarubia in Spain Vic Berchtesgaden near Brugg in Aargau, Aussee and Ischl in Austria Tarapaca in Peru, with 1 to [illegible] boracic acid

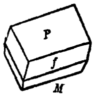


Fig 392

312 ANHYDRITE (*Karstenite*), CaS

Right prismatic ∞P 90° 4 Chiefly granular or almost compact or columnar Twins rare Cl macrodiagonal and brachydiagonal, both perfect basal perfect H = 3 to 3 5, G = 2 8 to 3 Transparent or translucent, vitreous on ∞P̆∞ pearly Colourless or white but often blue red or grey, streak greyish white C c 58 75 sulphuric acid and 41 25 lime

The crystalline or *Muriacite*, occurs in the salt mines of Bex Hall in Tyrol and Aussee in Styria, also at Sulz, Stassfurt, and Bleiberg Compact at Ischl in Austria, Berchtesgaden, Eisleben and the Harz Granular or *Vulpinite*, near Bergamo The contorted, or *Gekrosstein*, chiefly at Wieliczka and Bochnia

313 BARYTE (*Heavy Spar*) BaS

Right prismatic P̄∞ (*g*) 78° 20 P̆∞ (*f*) 105° 22, ∞P̆2 (*d*) 77° 44′ also ∞P̆∞ (*c*) (figs 125, 126 127 but in a different position *d d* being placed vertical) The crystals show very many forms and combinations and are tabular or columnar often in druses or groups, also foliated, fibrous granular or compact Cl brachydiagonal perfect, along P̆∞ less perfect, basal traces H = 3 to 3 5, G = 4 3 to 4 7 Transparent to translucent vitreous or resinous Colourless and white, but generally reddish white, or flesh red, yellow, grey bluish greenish or brown B B decrepitates violently, and fuses very difficultly or only on the edges, colouring the flame yellowish green not soluble in acids C c 34 3 sulphuric acid and 65 7 baryta, but occasionally with 1 to 15 sulphate of strontia Very common chiefly in veins, either alone or accompanying ores Crystals at Arran, Strontian, Elie, Sutherland, Dufton Bohemia, Felsobanya and Kremnitz in Hungary, Auvergne, and United States Columnar at Freiberg The radiated from near Bologna, or the *Bolognese Stone*, phosphoresces in the dark Massive, or *Cawk*, from Derbyshire and Staffordshire, Leadhills, and Arran

Lime Barytes, from Derbyshire, Strontian, Freiberg, seems a mixture with sulphate of lime, crystals tabular, in rosettes and other groups, G = 4 to 4 3 *Hepatite*, dark grey, from carbonaceous matter Kongsberg *Allomorphite*, scaly, white, and pearly, near Rudolstadt, agrees essentially with barytes

314 BARYTO CELESTINE $2\dot{S}rS + BaS$

Radiated and foliated Bluish white Brittle and friable H = 2 5, G = 3 92 Difficultly fusible Lake Erie, Upper Canada, and Binnenthal

315 CELESTINE SrS

Right prismatic, forms like barytes and anglesite P̆∞ (*o*) 104° 8 P̄∞ (*M*) 75° 58 Usual combinations P̆∞, P̄∞, ∞P̆∞, or this with ∞P2 (*d*), also columnar and foliated, or fibrous, fine granular, or compact Cl macrodiagonal perfect, along P̄∞ less perfect H = 3 to 3 5, G = 3 9 to 4 Transparent or translucent, vitreous or resinous Colourless, but usually bluish white to indigo blue and rarely reddish or yellowish B B decrepitates and fuses easily to a milk white globule, colours the flame carmine red Distinguished from barytes by a splinter, after ignition in the inner flame, on being moistened with h acid, and held in the blue border of the flame of a candle colouring this of a lively purple red Scarcely affected by acids C c 43 6 sulphuric acid and 56 4 strontia but often some baryta or lime Tantallon Castle Calton Hill Clachnaharry near Bristol and Knaresborough, sulphur mines of Girgenti and other parts of Sicily, Herrengrund in Hungary, Bex, Salzburg, Monte Viale near Verona, and Meudon and Montmartre near Paris Used for producing a red light in pyrotechnic mixtures

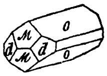


Fig 393

316 ANGLESITE, PbS

Right prismatic ∞P̆ 103° 43, P∞ 75° 35 The crystals of many forms and combinations, are short prismatic, pyramidal, or tabular Cl prismatic along ∞P, and basal, fracture conchoidal, very brittle H = 3 G = 6 2 to 6 35 Transparent or translucent adamantine or resinous Colourless and white, but occasionally yellow, grey, brown or blue, streak white Decrepitates in candle B B on charcoal fuses in the oxygen flame to a milk white bead very difficultly soluble in acids wholly in solution of potash C c 73 7 lead protoxide and 26 3 sulphuric acid Leadhills (fig 397), St Ives in Cornwall, Derbyshire, Parys mine in Anglesea, Zellerfeld, Klausthal, Badenweiler, Siegen, Silesia, Linares, Phœnixville in Pennsylvania

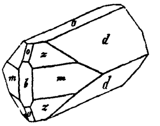


Fig 394

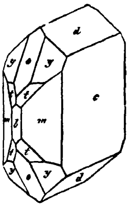


Fig 395

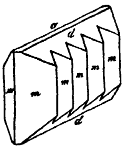


Fig 396

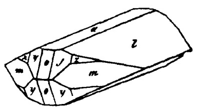


Fig 397

317 LANARKITE, $PbS + Pb$

Oblique prismatic ∞P 49° 50 Cl basal, perfect, sectile, thin laminæ flexible H = 2 to 2 5, G = 6 3 to 6 7 Transparent; resinous or adamantine, on 0P pearly. Greenish or yellowish white, inclining to grey, streak white B B on charcoal fuses to a white globule containing metallic lead, partially soluble in n.

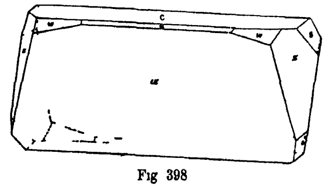


Fig 398

acid with effervescence C c sulphate of lead 57 6, oxide of lead 42 4 Leadhills, rare

HYDROUS SULPHATES

318 **Mirabilite** (*Glauber Salt*) Na_2S+10H_2

Oblique prismatic C 72° 15 Cl orthodiagonal, fracture conchoidal H = 1 5 to 2 G = 1 4 to 1 5 Pellucid and colourless C c 19 2 soda 24 8 sulphuric acid, and 56 water As an efflorescence in quarries on old walls or on the ground, in the waters of lakes and springs in Russia and Egypt and on Vesuvius on lava

319 **Gypsum**, $CaS+2H_2$

Oblique prismatic C 80° 57 The most common forms are ∞P 111° 30, P 138° 40, $-P$ 143° 30 and $\infty P^{c}\infty$ Two common combinations are ∞P(*f*) $\infty P^{c}\infty$ (*p*), $-P$ (*l*) (fig 129), and this with P Lenticular crystals often occur hemitropes frequent (figs 161, 150, 151), also granular, compact, fibrous scaly, or pulverulent Cl clinodiagonal perfect along P much less perfect, sectile thin plates flexible H = 1 5 to 2 (lowest on P) G = 2 2 to 2 4 Transparent or translucent, vitreous on cleavage pearly or silky Colourless, and snow white but often red, grey yellow brown, and more rarely greenish or bluish In the closed tube yields water B B becomes opaque and white soluble in 400 to 500 parts of water, scarcely more so in acids C c 46 5 sulphuric acid, 32 6 lime, and 20 9 water

Transparent crystals or *Selenite* occur in the salt mines of Bex in Switzerland, of the Tyrol, Salzburg and Bohemia in the sulphur mines of Sicily at Lockport in New York, in porphyry at Gourock in the clay of Shotover Hill near Oxford, at Chatley near Bath and many other localities Fibrous gypsum at Campsie, Matlock in Derbyshire and at Ilfeld in the Harz Compact gypsum in whole beds in many parts of England Germany, France and Italy at Volterra in Tuscany (*Alabaster*) often with rock salt The finer qualities (or alabaster) are cut into various ornamental articles

320 **Kieserite**, $MgS+H_2$

Rhombic but chiefly massive G = 2 52 Pellucid greyish white C c magnesia 29, sulphuric acid 58, water 13 In beds at Stassfurt

321 **Epsomite** (*Epsom Salt*) $MgS+7H$

Right prismatic P mostly hemihedric ∞P 90° 38 ∞P (*M*) $\infty\breve{P}\infty$ (*o*), P (*l*) (fig 399) Granular, fibrous, or earthy Cl brachydiagonal perfect H = 2 to 2 5 G = 1 75 Pellucid, vitreous and white Taste bitter C c 16 32 magnesia 32 53 sulphuric acid and 51 15 water Efflorescence on various rocks as at Hurlet near Paisley, Idria, Montmartre, and Freiberg on the ground in Spain and the Russian steppes, in mineral waters as at Epsom in Surrey, Saidschitz and Seidlitz in Bohemia Used in medicine

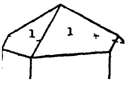


Fig 399 (sp 321)

322 **Goslarite** (*White Vitriol*), $ZnS+7H_2$

Right prismatic ∞P 90° 42, isomorphous with epsomite ∞P $\infty\breve{P}\infty$, P (*M* *o*, *l*) (fig 399) Mostly granular or stalactitic reniform and incrusting Cl brachydiagonal perfect H = 2 to 2 5, G = 2 to 2 1 Pellucid vitreous White inclining to grey, yellow, green or red Taste nauseous astringent C c 28 2 zinc oxide, 27 9 sulphuric acid, and 43 9 water Holywell in Flintshire, Cornwall, Rammelsberg near Goslar in the Harz, Falun, Schemnitz Used in dyeing and medicine

323 **Morenosite**, $NiS+7H_2$

Acicular, fibrous, and as an efflorescence H = 2 to 2 25 G = 2 Lustre vitreous Apple green, streak white Soluble Mor vein in Argyllshire, Cape Ortegal (Spain), Lake Huron, Pennsylvania

324 **Melanterite** (*Green Vitriol, Copperas*), $FeS+7H_2$

Oblique prismatic, C 75 45′ ∞P (*f*) 82° 22, $-P$ (P) 101° 34′, $P^{c}\infty$ (*o*) 67° 30′ (fig 400), chiefly stalactitic, reniform, or in crusts Cl basal perfect, prismatic less so H = 2, G = 1 8 to 1 9 Translucent, rarely transparent, vitreous Leek or mountain green, often with a yellowish coating, streak white C c 26 protoxide of iron, 29 sulphuric acid, and 45 water Hurlet near Paisley, Bodenmais, Rammelsberg, Falun, Schemnitz, Bilin Used in dyeing, and in manufacturing ink, Prussian blue, and sulphuric acid

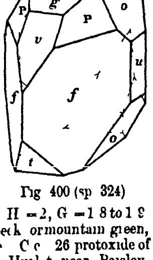


Fig 400 (sp 324)

325 **Smikite**, Mn_2S+H

Stalactitic aggregates Rose to white Felsobanya (Hungary)

326 **Mallardite**, $MnS+7H_2$

Crystalline foliated masses apparently oblique prismatic Lucky Bay mine in Utah

327 **Bieberite** (*Cobalt Vitriol*) $CoS+7H_2$

Oblique prismatic, usually stalactitic, or an efflorescence Pale rose red C c 20 cobalt oxide, 4 magnesia, 29 sulphuric acid, and 47 water Bieber near Hanau, and Leogang

328 **Alunogene** (*Hair Salt*), Al_2S+18H_2

Capillary or acicular in crusts or reniform masses H = 1 5 to 2 G = 1 6 to 1 7 Silky White, inclining to green or yellow C c 36 sulphuric acid, 15 4 alumina 48 6 water Volcanoes of South America, in coal and lignite in Germany, and on old walls

329 **Aluminite** (*Websterite*) $Al\,S+9H$

Reniform, and very fine scaly, or fibrous Fracture earthy, sectile or friable H = 1, G = 1 7 Opaque dull or glimmering, snow white or yellowish white C c 29 8 alumina, 23 2 sulphuric acid and 47 water Newhaven in Sussex, Epernay, Auteuil and Lunel Vieil in France Halle and Morl in Prussia *Felsobanyite*, from Hungary, in rhombic tables, is similar, but has 10 per cent of water

330 **Coquimbite** $Fe\,3S+9H$

Hexagonal P 58° Crystals 0P, with ∞P and P, usually granular Cl ∞P imperfect H = 2 to 2 5 G = 2 to 2 1 White also brown yellow red and blue C c 28 5 iron peroxide, 42 6 sulphuric acid and 28 9 water Copiapo in Chili, and Calama in Bolivia

331 **Copiapite** $2Fe\,5S+13H$

Six sided tables but system uncertain also granular Cl perfect Translucent pearly Yellow C c 34 iron peroxide, 42 sulphuric acid and 24 water Copiapo in Chili Also radiated-fibrous masses dirty greenish yellow incrusting the former, with 32 sulphuric acid and 57 water Both probably mixtures

Fibroferrite, also from Chili and *Yellow Iron Ore* from the brown coal at Kolosoruk in Bohemia and Modum in Norway are both reniform, or compact and earthy H = 2 5 to 3 G = 2 7 to 2 9 Colour ochre yellow *Apatelite* reniform earthy yellow, from Auteuil near Paris, is similar also *Vitriol Ochre* from Falun *Misy* from Rammelsberg in the Harz, containing sulphates of iron, copper, zinc and other metals, is a product of decomposition

332 **Pissophane**, $(Al_2Fe)S+15H$

Stalactitic, fracture conchoidal very easily frangible H = 2, G = 1 9 to 2 Transparent or translucent vitreous Olive green to liver brown, streak greenish white to pale yellow C c 7 to 35 alumina, 10 to 40 iron peroxide, 12 sulphuric acid and 41 water Saalfeld and Reichenbach in Saxony

Carphosiderite reniform opaque, resinous and straw yellow, with a greasy feel is related H = 4 5 G = 2 5 Consists of hydrous sulphate of iron Labrador

333 **Chalcanthite**, $CuS+5H$

Anorthic $\infty\bar{P}\infty$ (*n*) $\infty\breve{P}\infty$ (*r*) 79° 19 P (*P*) ∞P (*T*) 127° 40 *P* *n* 120° 50 *P* *r* 103° 27 ∞P (*T*) ∞P (*M*) 123° 10 (fig 401) Generally incrusting Cl *T* and *M* imperfect H = 2 5, G = 2 2 Blue C c 32 protoxide of copper, 32 sulphuric acid water Cornwall, Wicklow, Hungary, Tyrol, Falun, and on lava of Vesuvius

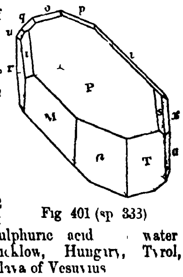


Fig 401 (sp 333)

334 **Brochantite**, $CuS+3CuH_2$

Right prismatic ∞P 104° 32, $\breve{P}\infty$ 152° 37 and $\infty\breve{P}\infty$ also reniform Cl brachydiagonal perfect H = 3 5 to 4, G = 3 75 to 3 9 Transparent or translucent, vitreous Emerald or blackish green streak bright green C c 70 copper protoxide, 18 sulphuric acid, and 12 water Sandlodge (Unst), Roughton Gill in Cumber-

Fig 402 (sp 334)

land, Rezbanya Ekaterinburg also Krisuvig in Iceland (*Krisuvigite*)

335 **Langite** $CuS+3CuH+2H_2$

Right prismatic ∞P 123° 44 Crystals long tabular, mostly in twins Also in fibro lamellar and concretionary crusts, with earthy surface Cl basal and brachydiagonal H = 2 5 G = 3 5 Vitreous Greenish blue C c 65 1 copper protoxide 16 4 sulphuric acid and 18 5 water Cornwall

Warringtonite is similar also *Konigine* from Siberia

336 **Johannite** (*Uran vitriol*)

Oblique prismatic C 85 40 ∞P 69° crystals similar to those (No 291 fig 383) but minute arranged in concretionary and reniform masses H = 2 to 2 5 G = 3 19 Semitransparent vitreous Soluble Taste bitter Bright grass green C c oxides of uranium 67 72 oxide of copper 5 99 sulphuric acid 20 02, water 5 59 Joachimsthal (Bohemia) Johann Georgenstadt

337 **Blodite** (*Astrakanite*) $(MgNa_2)S+2H$

Oblique prismatic C 100° 43 ∞P°2 112° [illegible] ∞P [illegible] ∞P°∞ (*b*) ∞P2 (*n*) ∞P∞ (*t*) P(*p*) P°∞ (*d*) 0P (*c*) (fig 403) In prismatic crystals or efflorescent H 3 5 G = 2 2 Transparent White or red C c 47 9 sulphuric acid 8 5 soda 12 magnesia and 21 5 water Salt lakes on the Volga near Astrakhan Ischl Stassfurt and near Mendoza in South America

[illegible] from Seidlitz is similar but a mixture

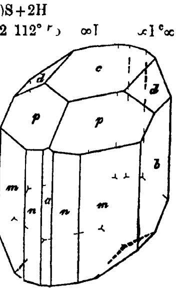


Fig 403 (sp 337)

338 **Loweite** $2(Na_2S+MgS)+5H$

Pyramidal but only compact Cl basal distinct also octahedral with angles 110° 44 and 105° 2 H = 2 5 to 3 G = 2 376 Vitreous Yellowish white to flesh red C c 20 soda 13 magnesia 52 sulphuric acid, and 15 water Ischl

339 **Syngenite** $K_2S+CaS+H_2$

Oblique prismatic C 76 ∞P 7[illegible] Crystals ∞P°∞ (*a*) ∞P°∞ (*b*) 0P (*c*) ∞P (*p*) ∞P°2 (*l*) ∞P°3 (*p*) 2P°2 (*e*) P (*o*) 2P (*o*) P°∞ (*q*) − P°∞ (*r*) P°∞ (*r*) 2P°∞ (*r*) − ⅔P°∞ (*e*) Cl ∞P perfect fracture conchoidal H = 2 5 G = 2 25 Colourless to milk white C c lime 16 85 potash 28 55 sulphuric acid 48 4 water 5 47 Soluble in 400 parts of water In cavities in halite at Kalusz (Galicia)

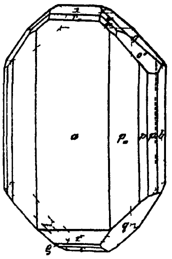


Fig 404 (sp 339)

340 **Polyhalite**, $2CaS+MgS+K_2S+2H_2$

Right prismatic ∞P 115° Mostly fibrous H = 3 5 G = 2 7 to 2 8 Translucent resinous Colourless generally brick red C c sulphate of lime 45 of magnesia 20 5, of potash 29 water 5 5 Ischl Aussee and Berchtesgaden

341 **Alum** $RS+(Al_2Fe_2)S_3+24H_2$

Cubic O sometimes with ∞O∞ and O∞ Generally efflorescent in fibrous crusts Cl octahedral fracture conchoidal H = 2 to 2 5 G = 1 7 to 1 9 Translucent White Taste sweetish astringent Soluble B B evolves sulphurous fumes (*a*) *Potash Alum* $RO=K_2O$ 33 7 sulphuric acid, 10 9 alumina 9 9 potash and 45 5 water In the coal formation at Hurlet and Campsie in Scotland the Tertiary brown coals of Hesse and the Rhine the Lias near Whitby Silurian alum slates of Scotland Norway and Sweden the volcanic formations of the Lipari Islands Sicily and the Azores (*b*) *Ammonia Alum* $RO=(NH_4O)$ about 4 per cent oxide of ammonium and 48 water In closed tube forms a sublimate of sulphate of ammonia Tschermig in Bohemia (*c*) *Soda Alum* $RO=Na_2O$ with 7 of soda and 48 water Mendoza in South America, Solfatara near Naples and Milo (*d*) *Magnesia Alum* $RO=MgO$ Translucent and silky South Africa Iquique in Peru (*Pickeringite*) (*e*) *Iron Alum* (*Feather Alum*) $RO=FeO$ Hurlet near Paisley, Morsfeld in Bavaria Krisuvig in Iceland (*f*) *Manganese Alum* $RO=MnO$ From Delagoa Bay in South Africa An alum with 3 7 oxide of zinc occurs at Felsobanya and has been termed *Dietrichite*

342 **Voltaite** $3(Fe, K_2)S+2(Fe_2Al_2)S+12H$

Cubic O ∞O∞, O∞ Black brown or green H = 3, G = 2 79 Solfatara near Naples, Goslar in the Harz, and Kremnitz

343 **Alunite** $K_2S+3Al_2S+6H_2$

Rhombohedral, R 89° 10 Crystals R and 0R (fig 405), also earthy Cl basal H = 3 5 to 4, G = 2 6 to 2 8 Translucent, vitreous pearly on O Colourless but often stained Hungary, Tolfa (near Civita Vecchia), Lipari Islands, Auvergne, and Milo

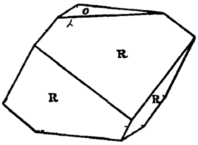


Fig 405 (sp 343)

344 **Jarosite**, $K_2S+Fe\,3S+2(Fe_23H_2)$

Rhombohedral, R 88° 58 Cl basal, also fibrous in nodules or incrusting H = 2 5 to 3 5, G = 3 24 Colour ochre yellow. Spain, Saxony, and Mexico

345 **Gelbeisenerz** $K_2S+4Fe\,S+9H_2$

Foliated and massive H = 2 5 to 3 G = 2 7 to 2 9 Bohemia, Norway, and Tcheleken Island in the Caspian Sea

346 **Urusite**, $Fe_2S+2Na_23S+8H_2$

Tcheleken Island in the Caspian

347 **Botryogene** (*Red Vitriol*) $Fe_3S_2+3(Fe_22S)+36H_2$

Oblique prismatic C 62° 26 ∞P 119° 56 Commonly botryoidal H = 2 to 2 5 G = 2 Translucent, vitreous Hyacinth-red and orange yellow Falun in Sweden

348 **Herrengrundite**

Oblique prismatic, C 88° 50 Dark emerald green crystals H = 2 5 G = 3 13 C c 57 22 oxide of copper 23 04 sulphuric oxide 19 44 water, sometimes with lime Herrengrund (Hungary)

349 **Linarite** $(PbS+H_2Pb)+(CuS+H_2Cu)$

Oblique prismatic C 77° 22 ∞P (*M*) 61° 41 2P°∞ (*u*) 52° 31′ Crystals ∞P°∞ (*a*) 0P (*c*) and the above forms generally Hemitropes united by ∞P°∞ (*a*) Cl orthodiagonal, perfect, fracture conchoidal H = 2 5 to 3 G = 5 2 to 5 45 Translucent, adamantine Azure blue to dark blue, streak pale blue C c oxide of lead 55 69, oxide of copper 19 83, sulphuric acid 19 98, water 4 5 Leadhills Red Gill and Roughton Gill (Cumberland), Linares in Spain, and Nertchinsk

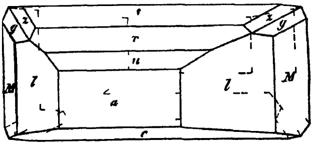


Fig 406

350 **Caledonite**, $5PbS+2(H_2Pb)+3(H_2Cu)$

Right prismatic ∞P (*m*) 95°, $\breve{P}\infty$ (*e*) 70° 57, $2\bar{P}\infty$ (*x*) 36° 10′. Crystals frequently as in fig 407, but generally hemihedral Cl brachydiagonal, *a* distinct *m*, *c* imperfect H = 2 5 to 3 G = 6 4 Transparent, resinous Verdigris green and mountain green streak greenish white C c 68 42 oxide of lead, 10 17 oxide of copper, 17 3 sulphuric acid, 4 05 water Leadhills Red Gill in Cumberland, Rezbanya in Transylvania

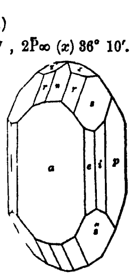


Fig 407 (sp 350)

351 **Lettsomite**, $3Cu_2S+2(Al_23H)+15H_2$

Right prismatic, but in tufts of capillary crystals with velvet like appearance Colour smalt blue to sky blue C c 49 oxide of copper, 2 97 lime, 11 21 alumina 1 41 oxide of iron 12 1 sulphuric acid 22 5 water Moldawa in the Banat *Woodwardite* is probably an aluminous variety of the above Turquoise blue to greenish blue Cornwall

352 **Kainite**, $MgS+KCl+3H$

Oblique prismatic, C 85° 5 (fig 408) G = 2 13 Cl orthodiagonal White to reddish C c 16 1 magnesia, 15 7 potash, 32 2 sulphuric acid, 14 3 chlorine, 21 7 water Stassfurt

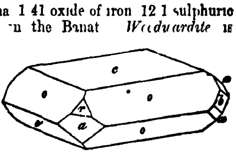


Fig 408 (sp 352)

TELLURATES AND CHROMATES

353 **Montanite**, $Bi_2Te+2\dot{H}_2$

Incrusting, earthy Lustre waxy Yellowish Opaque C c bismuth 66 8, tellurium 26 8, water 5 9 Highland in Montana

354 **Magnolite**, $HgTe$

White acicular crystals from Keystone mine in Colorado

355 **Crocoisite**, $PbCr$

Oblique prismatic, C 77° 27 ∞P 93° 42 (*M*), – P 119° 12′ (*t*), $\infty P^{c}2$ (*f*) 56° 10, $\infty P^{c}\infty$ (*g*) (fig 409) Cl ∞P, distinct, sectile H = 2 5 to 3, G = 5 9 to 6 1 Translucent, adamantine Hyacinth or aurora red streak orange yellow C c 31 chromic acid, and 69 lead protoxide Berezoff, Mursinsk, and Nijni Tagilsk in the Urals, Congonhas do Campo in Brazil, Rezbanya, Moldawa, and Tarnowitz Used as a pigment, but not permanent

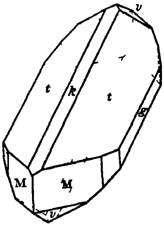


Fig 409 (sp 355)

356 **Phœnicochroite**, $2Pb\dot{C}r+\dot{P}b$

Right prismatic, dimensions unknown H = 3 to 3 5 G = 5 75 Translucent on the edges resinous or adamantine Cochineal to hyacinth red streak brick red C c 23 chromic acid, and 77 protoxide of lead Berezoff

357 **Vauquelinite**, $2(2PbCr+Pb)+(2CuCr+Cu)$

Oblique prismatic, C 67° 15 Crystals 0P P – $P^{\circ}\infty$ or *P f, h*) always twinned (fig 410), the faces of 0P forming an angle of 134° 30, also botryoidal or reniform H = 2 5 to 3, G = 5 5 to 5 8 Semi translucent or opaque resinous Blackish or dark olive green streak siskin green C c 61 lead protoxide, 11 copper protoxide 28 chromic acid Leadhills, Berezoff Congonhas do Campo (Brazil

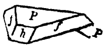


Fig 410

MOLYBDATES AND TUNGSTATES

358 **Wulfenite**, $PbMo$

Pyramidal P 131° 48′ 0P (*a*), $\frac{1}{3}$P (*l*), P, ∞P (*m*) P2 (*r*) (figs 411–414) Cl P, brittle, fracture uneven, or conchoidal H = 3, G = 6 3 to 6 9 Pellucid, resinous to adamantine Orange yellow, honey yellow, and colourless C c protoxide of lead 61 5, molybdic acid 38 5, red varieties have some chromic acid Lackentyre in Kirkcudbright (fig 412), Bleiberg, Rezbanya, Pennsylvania, Zacatecas $2PbOMoO_3$ + $CaOMoO_3$, with 6 88 of lime, occurs in Chili

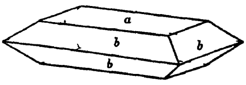


Fig 411

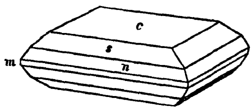


Fig 412

Fig 413 (sp 358)

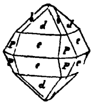


Fig 414 (sp 358)

359 **Eosite**

Pyramidal 0P (*c*) *p*′ 117° 10, *p*′ *p* 125° 40 (fig 415) H = to 4 Colour deep aurora red Streak orange yellow A vanadio molybdate of lead Leadhills

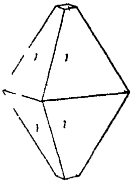


Fig 415 (sp 359)

360 **Megabasite**, Mg_4W_3

Oblique prismatic, similar to wolframite In fine needles H = 3 5 to 4, G = 6 45 to 6 97 Vitreous to adamantine Yellowish brown to brownish red, translucent hyacinth red, streak ochre yellow C c protoxide of manganese 23 1, protoxide of iron 5 4 tungstic acid 71 5 Schlaggenwald, Sadisdorf, Morococha in Peru

361 **Scheelite**, CaW

Pyramidal, with many of the modifying planes hemihedric P 113° 32′ Cl 2P∞ (*n*) 130° 33, perfect P and 0P less so Fracture conchoidal H = 4 to 4 5, G = 5 9 to 6 2 Translucent, resinous to adamantine Colourless, and grey, yellow, or brown, streak white C c. 19 4 lime, 80 6 tungstic acid Caldbeckfell near Keswick Pengelly in Cornwall, Zinnwald, Schlaggenwald, Salzburg, Chili, Siberia, Connecticut Employed for the extraction of yellow tungstic acid, a fine pigment

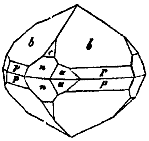


Fig 416 (sp 361)

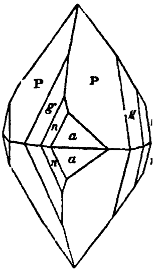


Fig 417 (sp 361)

Stolzite, PbW

Pyramidal, generally hemihedric P 131° 25 Crystals sometimes spindle shaped Cl P, imperfect H = 3, G = 7 9 to 8 1 Translucent, resinous Grey yellow, brown C c 48 4 protoxide of lead, 51 6 tungstic acid Keswick, Zinnwald, Coquimbo (Brazil)

363 **Reinite**, FeW

Pyramidal P 103° 32, basal angle 122° Cl ∞P H = 4, = 6 64 C c protoxide of iron 23 4, tungstic acid 75 45 Kimbosan in Japan

364 **Wolframite**, $(Fe, Mn)W$

Oblique prismatic, C 89° 22 ∞P (*M*) 100° 37, $-\frac{1}{2}P^{\circ}\infty$ (*P*) 1° 54, $P^{c}\infty$ (*u*) 98° 6 ∞P∞ (*r*), $\infty P^{\circ}2$ (*b*), – P (*a*), $2P^{c}2$ (*s*) Twins common Also laminar Cl clinodiagonal, perfect fracture uneven H = 5 to 5 5 G = 7 1 to 7 5 que resinous, metallic, adamantine the cleavage Brownish black streak black (varieties with most iron) to reddish brown (most manganese) C c 76 tungstic acid, 9 5 to 20 protoxide of iron, and 4 to 15 protoxide of manganese in some with 1 1 niobic acid East Pool Carnbrae and mines near Redruth Godolphin s Ball in Cumberland, Altenberg Geyer Ehrenfriedersdorf, Schlaggenwald, Zinnwald the Harz also Urals, Ceylon, and North America

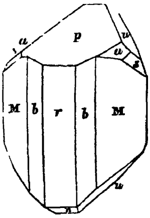


Fig 418

Ferberite with 26 protoxide of iron and $2Fe\dot{W}+\dot{F}e$ (H = 4 to 4 5, G = 6 7 to 6 8), from Spain, may be different

365 **Hubnerite**, MnW

Right prismatic ∞P (*M*) *M* : *M* 105° Cl ∞P̆∞, perfect, usually foliated or columnar H = 4 5 G = 7 14 Adamantine on cleavage elsewhere greasy Brown red streak yellow brown C c protoxide of manganese 23 4, tungstic acid 76 6 Mammoth district in Nevada

ANHYDROUS PHOSPHATES, ARSENIATES, AND VANADIATES

366 **Xenotime**, Y_3P

Pyramidal P 82° 22 middle angle polar angle 124° 30′ Crystals P, ∞P, ∞P∞ Cl ∞P H = 4 5, G = 4 6 to 4 55 Translucent in thin splinters, resinous Yellowish and flesh red C c 62 yttria and 38 phosphoric acid but some with 8 to 11 cerium protoxide Lindesnaes and Hittero in Norway, Ytterby (Sweden), Georgia, and (*Wiserine*) St Gotthard

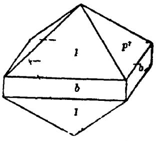


Fig 419 (sp 366)

367 **Cryptolite**, Ce_3P

Acicular crystals, embedded in apatite G = 4 6 Transparent Pale wine yellow Powder sol in cons acid Wohler found 73 70 cerium protoxide, 27 37 phosphoric acid, and 1 51 iron protoxide Occurs in the apatites of granite in Scotland, but not in those of limestones Also at Arendal

368 **Monazite**, $(Ce, La, Th)_3P$.

Oblique prismatic, C 76° 14 ∞P 23 crystals (fig 420) generally thick or tabular Cl basal, perfect translucent on edges Flesh red and reddish brown C c 28 phosphoric acid, 37 to 46 cerium protoxide, 24 to 27 lanthanum oxide that from Zlatoust from 18 to 32 5 of thoria Notero Norway, Miask, Norwich in Connecticut, and the Rio Chico in Colombia *Turnerite*, from Dauphine, in complex transparent honey yellow crystals, is monazite

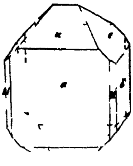


Fig 420 (sp 368)

369 **Triphylite** $(2\text{Fe}+\text{Li}_2)\text{P}_2$

Right prismatic ∞P 133° chiefly granular H = 5, G = 3 6 Resinous Greenish grey with blue spots C c iron protoxide 40, manganese protoxide 5 5, lithia 7 5, phosphoric acid 45 Bodenmais in Bavaria Norwich in Massachusetts *Lithiophilite*, from Fairfield (Connecticut) is a manganesian triphylite

370 **Berzeliite** (*Kühnite*) $(\text{Ca}\,\text{Mg})_3\text{As}_2$

Massive H = 5 to 6 G = 2 52 C c lime 23, magnesia 15, arsenic acid 60 Sol in n acid Långban (Sweden)

371 **Arseniate of Nickel** Ni_3As

Amorphous H = 4 G = 4 98 Sulphur yellow C c oxide of nickel 48 2, arsenic acid 50 5 Johann Georgenstadt

372 **Nickelerz**, $\text{Ni}_3\text{As}+2\text{Ni}$

Crystalline massive G = 4 84 Dark grass green, streak lighter C c oxide of nickel 62 1 arsenic acid 36 6 Johann Georgenstadt

373 **Dechenite**, $(\text{Pb}\text{Zn})\text{V}$

Botryoidal and stalactitic H = 3 to 4, G = 5 82 Lustre resinous to greasy Yellowish red, deep red, streak orange to pale yellow C c 57 7 oxide of lead, 15 8 oxide of zinc, 24 2 of vanadic acid Wanlockhead, Freiburg (in Baden), Lauter Valley

374 **Psittacinite**, $3(\text{Pb}_3\text{V})+\text{Cu}_3\text{V}_2+6\text{CuH}_2$

Mammillated and incrusting Siskin to olive green C c vanadic acid 19 3 lead oxide 53 2, copper oxide 18 95, water 8 58 Silver Star (Montana)

375 **Pucherite**, $\text{Bi}\,\text{V}$

Right prismatic ∞P 123° 55 H = 4, G = 6 25 Cl basal perfect vitreous Red or reddish brown streak yellow Easily soluble in acids C c bismuth oxide 71 7, vanadic acid 28 3 Schneeberg

376 **Atopite** $\text{Ca}\,\text{Sb}$

Cubic (figs 30 with 26 and 33) H = 5 5 to 6 G = 5 Lustre greasy yellow to resin brown Translucent C c antimonic acid 73 2, lime 17 5 iron protoxide 2 7, magnesia 1 5, soda 4 3 Långban (Wermland)

HYDROUS PHOSPHATES, &c

377 **Brushite**, $(\frac{2}{3}\text{Ca}+\frac{1}{3}\text{H})_3\text{P}_2+4\text{H}$

Oblique prismatic, C 62° 45 Needle crystals H = 2 to 2 5, G = 2 21 Vitreous C c lime 32 6, phosphoric acid 41 3, water 26 4 Aves Islands and Sombrero (Antilles)

378 **Newberyite** $\text{MgH}_2\text{P}+6\text{H}$

Right prismatic Cl brachydiagonal C c phosphoric acid 41 25, magnesia 23, water 35 7 From guano Skipton Caves, Victoria

379 **Haidingerite** $\text{Ca}\,\text{As}+3\text{H}$

Right prismatic ∞P 100° Cl perfect, sectile, flexible H = 2 to 2 5 G = 2 8 to 2 9 Otherwise like pharmacolite (sp 381) C c 85 68 arseniate of lime, and 14 32 water Joachimsthal

380 **Roselite** $\text{R}_3\text{As}+2\text{H}_2$

Anorthic Cl macrodiagonal Rose red, streak white H = 3 5, G = 3 46 C c 25 5 lime 10 3 cobalt oxide, 3 6 magnesia, 52 4 arsenic acid 8 2 water Schneeberg

381 **Pharmacolite** $2\text{CaAs}+6\text{H}$

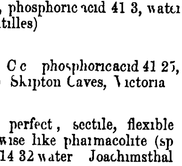


Fig 421

Oblique prismatic C 65° 4 (fig 421) ∞P (f) 117° 24, P (l) 139° 17, ½P (n) 141° 8, ½P°∞ (o) 83° 14, ∞P°3 (g) 157° 5 Crystals generally acicular and radiated Cl clinodiagonal, perfect sectile and flexible H = 2 to 2 5, G = 2 6 to 2 8 Translucent vitreous Pearly white Yields water in the closed tube C c arsenic acid 51, lime 25, water 24 Andreasberg Bieber, Markirchen, Wittichen Generally mixed with erythrite or annabergite

382 **Wapplerite**, $2\text{CaAs}+8\text{H}$

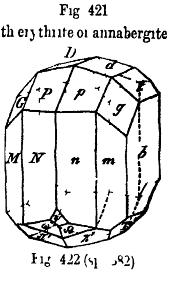


Fig 422 (sp 382)

Anorthic, ∞P (m) ∞P (M), ∞P̄ 2 (n), ∞P̄ 2 (N), P∞ (d), P∞ (D), ,P̆∞ (t) 3P̆∞ (T) 2P̄2 (p), 3P̆ (g), 3′P̆3/2 (G), 4P̄4 (ω) 2P̄2 (π), ∞P∞ (l) (fig 422), also incrusting and globular Cl clinodiagonal H = 2 to 2 5 G = 2 48 Colourless Vitreous C c lime 15 6, magnesia 7 4, arsenic acid 47 5, water 29 5 Joachimsthal

383 **Hornesite**, $\text{Mg}_3\text{As}_2+8\text{H}_2$

Oblique prismatic ∞P 107° H = 5 to 1, G = 2 47 White Translucent, pearly C c 24 3 magnesia, 29 14 water, 46 56 arsenic acid Probably from Hungary

384 **Vivianite**, $3\text{FeP}_2+8\text{H}_2$

Oblique prismatic, C 75° 34′ ∞P (m) 108° 2′, P (v) 120° 26′, P°∞ (w) 54° 40 Crystals prismatic (figs 423, 424), also fibrous or earthy Cl clinodiagonal, perfect, thin laminæ flexible H = 2, G = 2 6 to 2 7 Translucent or transparent, vitreous, or bright pearly on cleavage Indigo blue to blackish green streak bluish white, but soon becomes blue on exposure C c 33 1 iron protoxide, 12 2 iron peroxide, 29 phosphoric acid, and 25 7 water Transparent indigo coloured crystals at St Agnes in Cornwall, and Allentown and Imleytown in New Jersey, earthy in Cornwall, Styria, North America, Greenland, and New Zealand, and in peat mosses in northern Germany, Sweden, Norway, and Shetland

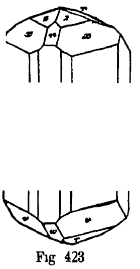


Fig 423

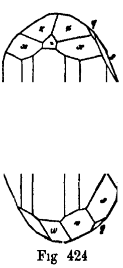


Fig 424

385 **Symplesite** $\text{Fe}_3\text{As}_2+8\text{H}$

Oblique prismatic, in minute acicular crystals Cl clinodiagonal H = 2 5, G = 2 96 Vitreous Cleavage face pearly. Celadon green to pale indigo, streak bluish white Lobenstein in Reuss, and Lolling in Carinthia

386 **Erythrite**, $\text{Co}_3\text{As}_2+8\text{H}_2$

Oblique prismatic, C 55° 9 ∞P°∞ (P), ∞P°∞ (T), P∞ (M) also ∞P3 (k) and P (l) 118° 23′ (fig 425) Cl clinodiagonal (P), perfect, sectile, thin laminæ flexible H = 1 5 to 2 5, G = 2 9 to 3 Translucent, vitreous, pearly on the cleavage Crimson or peachblossom red C c 38 2 arsenic acid 37 8 cobalt protoxide, 24 water, but often with nickel 9 Cornwall Alston in Cumberland, Alva in Stirlingshire Schneeberg, Saalfeld, Allemont, Riechelsdorf, the Pyrenees, and Modum in Norway *Kobaltbeschlag* or *Earthy Incrusting Cobalt* reniform, is a mixture of erythrine with arsenious acid *Lavendulan*, thin reniform lavender blue crusts, translucent, resinous, or vitreous (H = 2 5 to 3, G = 2 95 to 3 1), consisting of arsenic acid, protoxides of cobalt, nickel, and copper, with water; from Annaberg

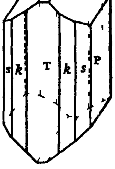


Fig 425

387 **Köttigite**, $(\text{Zn},\text{Co},\text{Ni})_3\text{As}+8\text{H}$

Oblique prismatic, massive or in crusts, with crystalline surface and fibrous structure Cl clinodiagonal, perfect H = 2 5 to 3, G = 3 1 Lustre of fracture silky Colour light carmine and peachblossom red, of different shades, streak reddish white Translucent to subtranslucent C c 30 52 zinc oxide 6 91 cobalt oxide, 2 nickel oxide, with arsenic acid Schneeberg

388 **Annabergite** (*Nickel Ochre*), $\text{Ni}_3\text{As}+8\text{H}_2$

Oblique prismatic, in capillary crystals, also earthy, sectile H = 2 to 2 5, G = 3 to 3 1 Dull or glistening Apple-green or greenish white, streak greenish white and shining C c. 38 7 arsenic acid, 37 3 nickel protoxide, and 24 water, but with a little cobalt or iron Leadhills, Pibble in Kirkcudbright, Andreasberg, Saalfeld, Riechelsdorf

389 **Ludlamite**, $\text{Fe}_7 2\text{P}+9\text{H}_2$

Oblique prismatic, C 79° 27 ∞P 131° 23, 0P, P 111° 29′ (fig 426) Cl 0P, perfect H = 3 5, G = 3 12 C c 53 05 oxide of iron, 29 88 phosphoric acid, 17 0 water Cornwall

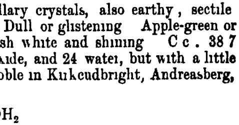


Fig 426 (sp 389)

390 **Fillowite**, $3(\text{R}_3\text{P}_2)+\text{H}_2$

Oblique prismatic, C 89° 51, pseudo rhombohedral P, −2P̄8, 0P Cl basal H = 4 5, G = 3 43 Resinous to greasy Wax yellow to red brown, or colourless streak white, translucent C c phosphoric acid 40·2, iron protoxide 6 8, manganese protoxide 40 2, lime 5 2, soda 5 8, water 1 7. Branchville (Connecticut)

391 **Hureaulite**, $5(\text{Mn},\text{Fe})2\text{P}_2+5\text{H}_2$

Oblique prismatic, C 89° 27′ ∞P 61° Fracture conchoidal. H = 3 5, G = 3 2 Translucent, resinous Reddish yellow or brown B B fuses easily to a black metallic globule Soluble in acids C c 39 phosphoric acid, 8 iron protoxide, 42 manganese protoxide, and 12 water Hureaux near Limoges

Heterozite H =5, G =3 5 Opaque, vitreous or resinous Dark violet or blue to greenish grey, streak violet blue or crimson red Contains more iron and less manganese than the above Hureaux

392 DICKINSONITE, $4(R_3P_2)+3H_2$

Oblique prismatic, C 60° 30 Crystals tabular Cl basal, perfect H =3 5 to 4, G =3 34 Vitreous, pearly on cleavage Olive to oil green, and grass green, streak white Transparent, brittle C c phosphoric acid 40, iron protoxide 12 7 manganese protoxide 25, lime 11 8, soda 6 6, water 3 8 Branchville (Connecticut)

393 TRIPLOIDITE, $(Mn, Fe)_3P+H(Mn, Fe)_2$

Oblique prismatic, C 51° 56 Generally fibrous transparent resinous to adamantine H =4 5 to 5, G =3 7 Yellowish brown C c 48 45 oxide of manganese, 14 88 protoxide of iron, 32 1 phosphoric acid, 4 1 water Fairfield (Connecticut)

394 FAIRFIELDITE, R_3P_2+2H

Anorthic, usually foliaceous H =3 5 G =3 15 White to straw yellow, streak white Pearly to brilliant adamantine on cleavage Transparent, brittle C c phosphoric acid 38 4, iron protoxide 5 6, manganese protoxide 15 6 lime 30, soda 7, water 10 Fairfield (Connecticut)

395 CHONDRARSENITE, $Mn_5As_2+\frac{5}{4}H$

In small grains H =3 Yellow to reddish yellow Translucent, brittle, fracture conchoidal Paisberg mines (Wermland)

396 REDDINGITE, $Mn_3P_2+3H_2$

Right prismatic P, $\bar{P}2$ $\infty\breve{P}\infty$ H =3 to 3 5 G =3 1 Vitreous, rose pink to yellowish white Translucent fracture uneven, brittle C c phosphoric acid 34 5, iron protoxide 5 43 manganese protoxide 46 3, lime 8 water 13 1 Branchville

397 SCORODITE, Fe_2As+4H_2

Right prismatic P with polar edges 102° 52 and 114° 40 Crystals P (*p*), $\infty\bar{P}\infty$ (*a*), and $\infty\breve{P}\infty$ (*b*) also 0P, $\frac{1}{2}$P (*i*), ∞P (*n*) $2\breve{P}2$ (*s*), $\infty\breve{P}2$ (*d*) 120° 10, and $2\bar{P}\infty$ (*m*) 132° (fig 427) also columnar and fibrous Cl imperfect, brittle H =3 5 to 4 G =3 1 to 3 2 Translucent vitreous Leek green to greenish black also indigo blue, red, and brown B B fuses easily with arsenical odour to a grey magnetic slag Sol in h acid to a brown solution C c 49 8 arsenic acid 34 6 iron peroxide, and 15 6 water St Austell in Cornwall, near Limoges in France Schwarzenberg, Lolling in Carinthia Brazil, and Siberia

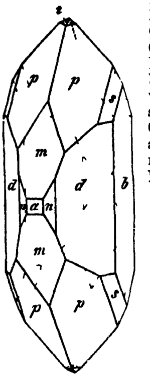


Fig 427 (sp 397)

398 STRENGITE, Fe P +4H,

Right prismatic P with polar edges 101° 38 and 115° 36, middle edge 111° 30 $\infty\breve{P}2$ (*d*) and $\infty\bar{P}\infty$ (*r*) P (*P*), 0P (*h*), $2\bar{P}\infty$ (*m*) 48° (fig 428) Crystals generally *r*, *P*, *d*, *r* dominant Cl *r* H =3 to 4, G =2 87 Cherry red Translucent C c protoxide of iron 43 18, phosphoric acid 37 42, water 19 4 Rock Bridge (Virginia)

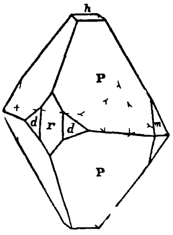


Fig 428 (sp 398).

399 DUFRENITE (*Kraurite*), $2Fe_2P+3H_2$

Right prismatic ∞P about 123° Spherical or reniform Cl brachydiagonal, brittle H =3 to 3 5, G =3 3 to 3 4 Translucent on the edges, or opaque, shining or dull Dirty leek green or blackish green, streak siskin green C c 63 iron peroxide 28 phosphoric acid, and 9 water Westerwald, Hirschberg, and Limoges

400 BERAUNITE, $5Fe_23P+14H_2$

Occurs in small foliated and columnar aggregates Cl plane metallic pearly H =2, G =2 878 Colour hyacinth red to reddish brown, streak dirty yellow C c 54 5 peroxide of iron, 28 65 phosphoric acid, and 16 55 water Bohemia, Scheibenberg in Saxony

401 ELEONORITE, $3Fe_22P_2+8H_2$

Oblique prismatic C 48° 33 Twin face the orthopinacoid Cl ∞P°∞ H =3 to 4 Dark hyacinth red, streak yellow Vitreous to pearly C c 51 94 peroxide of iron, 31 88 phosphoric acid, 16 37 water Eleonore mine near Bieber

402 CACOXENE, $2Fe_2P_2+12H$

Radiated tufts, of a brownish yellow colour H =3 to 4, G =3 38 Sol in h acid From the Hibeck mine near Zbirow in Bohemia

403 PHARMACOSIDERITE (*Cube Ore*), $4Fe\,3As_2+15H_2$.

Cubic and tetrahedral usually ∞O∞, with $\frac{O}{2}$, or ∞O Brittle H =2 5 G =2 9 to 3 Cl ∞O∞ Semitransparent to translucent, adamantine or resinous Olive to emerald green, honey-yellow, and brown, streak straw yellow Pyro electric C c 43 arsenic acid, 40 iron peroxide, and 17 water Carharrack in Cornwall, Burdle Gill in Cumberland, Lobenstein in Reuss Schwarzenberg in Saxony, North America, and the gold quartz of Australia

404 CALAITE (*Turquoise*), $2(Al_2)P+5H$

Massive reniform, or stalactitic, fracture conchoidal H =6, G =2 6 to 2 8 Opaque or translucent on the edges, dull or waxy Sky blue, greenish blue rarely green streak greenish white C c 47 alumina, 32 5 phosphoric acid, and 20 5 water, but mixed with phosphate of iron and copper Silesia Lusatia, and Reuss Oriental turquoise in veins, at Meshed near Herat in pebbles in Khorassan Bokhara, and Syrian desert Takes a fine polish, and valued as an ornamental stone, but is destroyed by oil, and deteriorated by soap

405 WAVELLITE (*Lasionite*), $3Al_22P+12H_2$

Right prismatic ∞P 126° 25, $\bar{P}\infty$ 106° 46 Crystals ∞P∞ (*P*) ∞P (*d*) $\bar{P}\infty$ (*o*) (fig 429) but generally small, acicular, and in radiated hemispherical and stellate fibrous masses Cl along ∞P and $\bar{P}\infty$ perfect H =3 5 to 4, G =2 3 to 2 5 Translucent, vitreous Colourless, but generally yellowish or greyish, sometimes green or blue C c 38 alumina 35 3 phosphoric acid, and 26 7 water but generally traces of fluoric acid (2 per cent) Shiant Islands and Glencoe in Scotland Barnstaple St Austell, near Clonmel and Portrush, Beraun in Bohemia, Amberg in Bavaria, also in New Hampshire and Tennessee *Cœruleolactin*, from Nassau, has two equivalents less of water

Fig 429

406 VARISCITE Al P+4H

Right prismatic, reniform, conchoidal fracture H =4 to 5, G =2 34 to 2 38 Apple and emerald green, streak white C c 32 4 alumina, 44 85 phosphoric acid 22 74 water Messbach in Reuss, Montgomery county in Arkansas

Zepharovichite from Bohemia contains one equivalent more water, *Evansite* from Hungary two equivalents more

407 FISCHERITE, $2Al_2P+8H_2$

Right prismatic ∞P 118° 32, generally in crystalline crusts H =5, G =2 46 Grass and olive green Vitreous lustre C c alumina 42, phosphoric acid 29, water 29 Nijni Tagilsk.

408 PEGANITE, $2Al_2P+6H_2$

Right prismatic ∞P 127° In thin reniform crusts, of fibrous structure H =3 to 4, G =2 49 to 2 54 Grass and emerald green Vitreous or greasy lustre C c alumina 45, phosphoric acid 31 3, water 23 7 Striegis in Saxony

409 HOPEITE, Zn_3P+4H

Right prismatic $\infty\breve{P}2$ 82° 20, P with polar edges 106° 36 and 140° Cl macrodiagonal perfect H =2 5 to 3 G =2 76 to 2 85 Vitreous or pearly Greyish white C c oxide of zinc 35 21, phosphoric acid 31 1, water 15 8 Altenberg

410 ADAMITE $4\dot{Z}nAs+H$

Right prismatic ∞P 91° 52 Cl macrodomic H =3 5, G =4 34 Lustre vitreous Colour honey yellow to violet, streak white Transparent C c oxide of zinc 56 6, arsenic acid 40 2 water 3 2 Cape Garonne in France, Chanarcillo in Chili

411 LIBETHENITE $4CuP_2+6H_2$

Right prismatic ∞P (*u*) 92° 20′, $\breve{P}\infty$ (*o*) 109° 52, and P (fig 430) H =4 G =3 6 to 3 8 Translucent on the edges resinous Leek, olive, or blackish green, streak olive green C c 66 copper protoxide, 30 phosphoric acid, and 4 water Gunnislake (Devon), Libethen (Hungary) Nijni Tagilsk

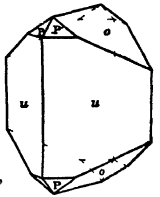


Fig 430 (sp 411)

412 OLIVENITE, $4Cu(As_2P_2)+H_2$

Right prismatic $\infty(P)$ (*r*) 92° 30, $\breve{P}\infty$ (*l*) 110° 50, ∞P (*n*) (fig 431), also spherical and reniform, and columnar or fibrous Cl (*r*) and (*l*), imperfect H = 3 G = 4 1 to 4 6 Pellucid in all degrees, vitreous resinous or silky Leek, olive, or blackish green, also yellow or brown, streak olive green or brown B B in the forceps fuses easily to a dark brown adamantine bead, covered with radiating crystals on charcoal detonates, emits arsenical vapours, and is reduced Sol in acids and ammonia C c 56 5 copper protoxide, 39 5 arsenic acid and 4 water but also 1 to 6 phosphoric acid Carharrack, Tin Croft, Gwennap and St Day in Cornwall Alston Moor, Thuringia, Tyrol, Siberia, Chili

Fig 431

413 VESZELYITE $9Cu\,6Zn, P\,As+18H_2$

Oblique prismatic, C 103° 50 H = 3 5 to 4 G = 3 53 Greenish blue C c copper 37 34 25 20 zinc oxide 10 41 arsenic acid, 9 01 phosphoric acid, 17 05 water Moravicza (Banat)

414 DESCLOIZITE, $2PbV+H$

Right prismatic ∞P 116° 25 H = 3 5 G = 5 86 to 6 1 Olive brown to black C c 56 48 oxide of lead, 16 6 oxide of zinc 1 16 oxide of manganese 22 74 vanadic acid Sierra de Cordoba in the Argentine Republic

415 VOLBORTHITE $4(Cu, Ca)V_2+H$

Hexagonal small tabular crystals, 0P, ∞P, single or in groups Generally massive. H = 3, G = 3 45 to 3 89 Olive green, streak almost yellow B B on charcoal fuses easily and forms a graphite like slag, containing grains of copper Sol in n acid, and with water gives a brick red precipitate C c 37 to 38 vanadic acid 39 4 to 46 copper oxide, 18 5 to 13 lime 3 6 to 5 water Sissersk (Urals) Nijni Tagilsk, and Friedrichroda in Thuringia

416 TAGILITE $4CuP+3H$

Oblique prismatic, but botryoidal and radiating fibrous, or earthy H = 3 G = 4 Emerald green C c 61 8 copper protoxide 27 7 phosphoric acid, and 10 5 water Nijni Tagilsk, and near Hirschberg

417 EUCHROITE $4CuAs+7H$

Right prismatic ∞P (*M*) 117° 20, $\breve{P}\infty$ (*n*) 80° 52, with $\infty\breve{P}2$ (*l*) and 0P (*P*) (fig 432) Brittle H = 3 5 to 4, G = 3 35 to 3 45 Translucent vitreous Emerald or leek green, streak verdigris green B B in forceps fuses to a greenish brown crystallized mass Easily sol in n acid C c 47 copper protoxide, 34 arsenic acid, and 19 water Libethen in Hungary

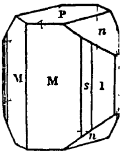


Fig 432 (sp 417)

418 ERINITE $5CuAs+2H$

Reniform and foliated conchoidal fracture H = 4 5 to 5 G = 4 to 4 1 Translucent on the edges dull resinous Emerald or grass green streak similar C c 59 9 copper protoxide 34 7 arsenic acid, and 5 4 water Cornwall *Cornwallite* has 3 or 5 of water

419 DIHYDRITE $5CuP_2+2H_2$

G = 4 4 Oxide of copper 69 phosphoric acid 24 7, water 6 25 Rheinbreitenbach and Nijni Tagilsk

420 MOTTRAMITE, $5(Cu, Pb)V+2H_2$

Black crystalline crusts, streak yellow H = 3, G = 5 9 C c oxide of copper 20 4, oxide of lead 7 2 vanadic acid 18 7, water 3 7 Mottram in Cheshire

421 EHLITE $5CuP+3H$

Right prismatic botryoidal radiating foliated H = 1 5 to 2, G = 3 8 to 4 27 Translucent on the edges, pearly on the cleavage Verdigris green streak paler C c 67 copper protoxide, 24 phosphoric acid, and 9 water Ehl on the Rhine, Nijni Tagilsk, Libethen

422 TYROLITE $5CuAs+9H$

Right prismatic Cl basal perfect reniform Radiate foliaceous H = 1 5 to 2 G = 3 Lustre pearly on cleavage face Colour apple green and verdigris green to sky blue, streak paler Sub translucent C c oxide of copper 50 3 arsenic acid 29 2, water 20 5 Tyrol, Hesse, Thuringia

423 PHOSPHOROCHALCITE (*Lunnite*) $6CuP+3H_2$

Oblique prismatic Crystals $\infty P^{\circ}2$ (*f*) 38° 56, P (*P*) 117° 49, with 0P (*a*) and $\infty P^{\circ}\infty$ (*e*) (fig 433), usually small and indistinct, more common in spherical or reniform and radiated fibrous masses H = 5, G = 4 1 to 4 3 Translucent throughout or on the edges, adamantine to resinous Blackish, emerald, or verdigris green C c 70 8 copper protoxide, 21 2 phosphoric acid, and 8 water Cornwall, Rheinbreitenbach, Nijni Tagilsk

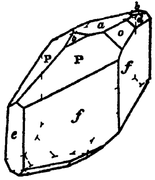


Fig 433 (sp 423)

424 CLINOCLASE, $6CuAs_2+3H_2$

Oblique prismatic, C 80° 30′ 0P (*P*), ∞P (*m*) 56°, $\frac{3}{2}P^{\circ}\infty$ (*a*) 99° 30, (*r*) 123° 48 (figs 434, 435), and hemispherical Cl basal, perfect H = 2 5 to 3, G = 4 2 to 4 4 Translucent, vitreous, pearly on cl Dark verdigris green to sky blue, streak blue C c 62 6 copper protoxide, 30 3 arsenic acid, 7 1 water Cornwall, Tavistock, Erzgebirge

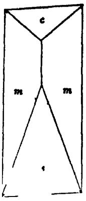


Fig 434 (sp 424)

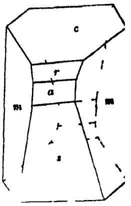


Fig 435 (sp 424)

425 MIXITE

Oblique prismatic or anorthic (?) Radiating, centrally granular ∞P 125° H = 3 to 4, G = 2 66 Emerald green to blue green, streak paler C c 43 21 copper oxide, 13 1 bismuth oxide, 30 45 arsenic acid, 11 1 water Geistergang, Joachimsthal.

426 RHAGITE, $5Bi_2\,2As_2+8H_2$

Grape like groups of minute crystals Colour yellowish green, streak white Lustre wax like, brittle H = 5, G = 6 82 C c bismuth oxide 79 5, arsenic acid 15 6, water 4 9 Neustadtel near Schneeberg

427 TROGERITE, $3UAs_2+12H_2$

Oblique prismatic, C 80° Crystals thin tabular Cl clinodiagonal, perfect Lustre pearly G = 3 3 Lemon yellow C c 65 95 oxide of uranium, 17 56 arsenic acid, 16 49 water In closed tube gives off water, and becomes golden brown, but again yellow on cooling Neustadtel

428 STRUVITE, $(NH_4, 2Mg)P_2+12H_2$

Right prismatic $\bar{P}\infty$ (*a*) 63° 7, $\breve{P}\infty$ (*c*) 95°, $4\breve{P}\infty$ (*b*) 30° 32′, $\infty\breve{P}\infty$ (*n*), $\frac{1}{3}\bar{P}\infty$ (*m*) 123°, 0P (*o*) (fig 436) Cl brachydiagonal, perfect H = 1 5 to 2, G = 1 66 to 1 75 Transparent or opaque, vitreous Colourless, but yellow or brown C c 29 9 phosphoric acid, 16 3 magnesia, 10 6 ammonia, and 44 water Under St Nicholas church at Hamburg, and in guano from South America

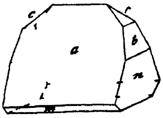


Fig 436

429 ARSENIOSIDERITE, $3CaAs_2+3Fe_2As_2+6H_2$

Spherical and fibrous, friable H = 1 2, G = 3 52 to 3 88 Opaque silky Golden yellowish brown, streak yellowish brown C c peroxide of iron 39 4, lime 13 8, arsenic acid 37 9, water 8 9 Romaneche near Macon

430 CHALCOSIDERITE

Anorthic Light green crystals G = 3 11 C c 42 8 peroxide of iron, 8 1 oxide of copper, 4 45 alumina, 30 54 phosphoric acid, 15 water Cornwall

431 LAZULITE, $Al_2P_2+(Mg, Fe)_3P_2+2H_2$

Oblique prismatic, C 88° 2 ∞P 91° 30, P (*e*) 99° 40′, −P (*p*) 100° 20 Crystals often tabular through distortion, twins on 0P, and $\infty P^{\circ}\infty$, also massive, fracture splintery Cl ∞P H = 5 to [illegible], G = 3 to 3 1 Translucent, vitreous white In closed tube yields water, and loses colour Soluble in acids after ignition C c 31 7 alumina, 10 magnesia, 6 protoxide of iron, 44 phosphoric acid, and 6 water Salzburg, Styria, Brazil, Georgia, Lincoln in North Carolina.

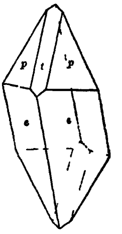


Fig 437 (sp 431)

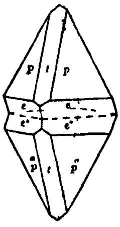


Fig 438 (sp 431)

432 Childrenite, $2(\dot{Fe}, Mn)_4\bar{P} + \bar{Al}\bar{P} + 15\bar{H}$ $\bar{P} = P$, $\bar{H} = H$, &c

Right prismatic Polar edges 101° 43′, 130° 10′, middle 98° 44 usual form $\breve{P}$, $2\breve{P}\infty$, $\infty P\infty$ (*e*, *a*, P, fig 439) H = 4 5 to 5, G = 3 18 to 3 3 Translucent vitreous Yellowish white to wine or ochre yellow brown, or almost black C c 30 7 iron protoxide, 9 manganese protoxide, 14 5 alumina, 29 phosphoric acid, and 17 water Tavistock, Crinnis and Callington (Cornwall)

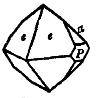


Fig 439

433 Eosphorite $(Fe, Mn)_2\bar{Al}, \dot{P} + 4\bar{H}$

Right prismatic P (*p*) 133° 32 and 118° 56, ∞P (*i*) 104° 19, $\infty\bar{P}\infty$ (*a*), $\infty\breve{P}\infty$ (*b*), $\infty\breve{P}2$ (*g*), $\frac{3}{2}\breve{P}\frac{3}{2}$ (*q*), $2\breve{P}2$ (*s*) (polar edges 130° 26 and 98° 42) (fig 440) Cl macrodiagonal H = 5, G = 3 13 Pale red Vitreous C c 22 alumina, 7 4 protoxide of iron, 23 5 oxide of manganese, 31 5 phosphoric acid, 15 6 water Fairfield (Connecticut)

434 Liroconite, $Cu_8\dot{As} + \bar{Al}\dot{As} + 24\bar{H}$

Oblique prismatic, C 88° 33 ∞P (*d*) 61° 31, $P^{e}\infty$ (*o*) 74° 21 (fig 349) H = 2 to 2 5 G = 2 8 to 3 Translucent, vitreous or resinous Azure blue to verdigris green, streak paler C c 36 6 protoxide of copper, 11 9 alumina, 26 6 arsenic acid, 24 9 water Redruth, Herrengrund in Hungary

Fig 440 (sp 433)

435 Chalcophyllite, $Cu_6\dot{As} + 12\bar{H}$

Hexagonal rhombohedral, R 69° 48 (fig 441) Cl basal, perfect, sectile H = 2, G = 2 4 to 2 6 Transparent vitreous to adamantine Pearly on 0R (*o*) Emerald to grass and verdigris green streak pale green Soluble in acids and ammonia C c protoxide of copper 49 6, arsenic acid 18 water 32 4 Redruth in Cornwall Saida in Saxony, Moldawa in the Banat

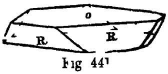


Fig 441

436 Uranite, $(Ca, \bar{U}_2)\bar{P} + 8\bar{H}$

Right prismatic ∞P 90° 43, P middle edge 127° 32 0P P 116 14 0P $2\bar{P}\infty$ 109° 6, 0P $2\breve{P}\infty$ 109° 19′ (figs 442 443 Crystals flat Cl basal, perfect, sectile H = 1 to 2, G = 3 to 3 2 Translucent pearly on 0P Sulphur yellow to siskin green streak yellow C c 15 5 phosphoric acid, 62 6 uranium peroxide, 6 1 lime, and 15 8 water Cornwall, Autun and Limoges in France Johann Georgenstadt and Eibenstock in Saxony, Chesterfield in Massachusetts

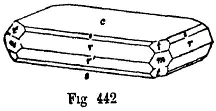


Fig 442

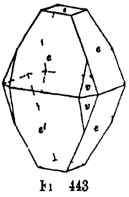


Fig 443

437 Uranospinite, $(Ca, \bar{U})\dot{As} + 8\bar{H}$

Right prismatic quadrangular, scale like crystals Cl basal, perfect H = 2 3, G = 3 45 Siskin green C c lime 5 47, sesquioxide of uranium 59 18, arsenic acid 19 37, water 16 29 Neustadtel

438 Uranocircite, $(Ba, \bar{U}_2)\bar{P} + 8\bar{H}$

Yellowish green crystals, isomorphous with 437 Cl basal G = 3 53 C c sesquioxide of uranium 56 86 baryta 14 57, phosphoric acid 15 1, water 14 Falkenstein in Voigtland

439 Chalcolite, $(\dot{Cu}, \bar{U}_2)\bar{P} + 8\bar{H}$

Pyramidal P middle edge 142° 8, $P\infty$ 128° 14 Crystals 0P, P, $\infty P\infty$, $P\infty$ Cl basal, perfect pearly lustre, brittle H = 2 to 2 5, G = 3 5 to 3 6 Grass to emerald or verdigris green, streak apple green C c 15 2 phosphoric acid 61 uranium peroxide, 8 5 copper protoxide, and 15 3 water Redruth and St Austell, Johann Georgenstadt, Eibenstock, Schneeberg Bodenmais, Baltimore

440 Zeunerite, $(Cu, \bar{U}_2)\dot{As} + 8\bar{H}$.

Pyramidal P middle edge 142° 6′ 0P P 109° 57 Crystal tabular Cl basal H = 2 5, G = 3 53 Grass green Lustre pearly C c 7 7 oxide of copper, 55 95 sesquioxide of uranium 14 water Huel Gorland in Cornwall, Neustadtel, Joachimsthal, Zinnwald, Wittichen

441 Walpurgite, $5\bar{Bi}\dot{As} + 3\bar{U}\dot{As} + 10\bar{H}$

Anorthic, in scaly crystals Wax yellow to pomegranate red Adamantine to greasy H = 3 5, G = 5 76 C c sesquioxide of bismuth 60 4 sesquioxide of uranium 20 4, arsenic acid 13, water 4 5 Neustadtel

442 Plombgomme, $Pb_3\bar{P} + 6\bar{Al}\bar{H}_3$

Reniform or stalactitic, fracture conchoidal and splintery H = 4 to 4 5, G = 6 3 to 6 4 Translucent, resinous Yellowish or greenish white to reddish brown C c 38 protoxide of lead, 35 alumina, 8 phosphoric acid, and 19 water, but with 2 chloride of lead Poullaouen, Nuissiere (near Beaujeu), Georgia

Compounds of Phosphates, Vanadiates, and Arseniates with Haloid Salts

443 Apatite, $3Ca\bar{P} + Ca(Cl, F)$

Hexagonal and pyramidal hemihedric P 80° 26 The most common forms are ∞P (M), $\infty P2$ (*n*) 0P (*m*) P (*x*) the base 0P seldom wanting (figs 92, 95, 96, 97, 98) The crystals are short prismatic or thick tabular, also granular, fibrous, or compact, fracture conchoidal or splintery, brittle H = 5, G = 3 1 to 3 25 Transparent to opaque, vitreous to resinous Colourless and white, but generally light green, grey, blue, violet or red C c phosphate of lime (89 to 92 3), with chloride (to 11) or fluoride (to 7 7) of calcium, or both Disseminated in granite, gneiss, mica and hornblende slates, primary limestones, and trap rocks, also in beds and veins Sutherland, Ross, and Aberdeen, in granite and limestone, Cumberland, Devonshire and Cornwall in tin mines in Saxony, Bohemia, St Gotthard, Tyrol, Krageroe in Norway, New York, Canada

444 Pyromorphite $3Pb_3\bar{P} + PbCl$

Hexagonal P 80° 44 Crystals ∞P, 0P, with $\infty P2$ or P (*M*, *P*, *x*, fig 444) occasionally thicker in the middle, or spindle shaped, also reniform or botryoidal fracture conchoidal or uneven H = 3 5 to 4, G = 6 9 to 7 Translucent resinous or vitreous Colourless, but generally grass, pistachio, olive or siskin green, and clove or hair brown and scarlet (Leadhills) C c 89 7 phosphate and 10 3 chloride of lead but with 0 to 9 arseniate of lead, 0 to 11 phosphate of lime, and 0 to 1 fluoride of calcium Elgin, Wanlockhead also Cornwall Derbyshire, Yorkshire, Durham, Cumberland, Wicklow Przibram Mies and Bleistadt in Bohemia, Berezoff, Phœnixville in Pennsylvania and Mexico

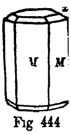


Fig 444

445 Vanadinite, $3Pb_3\bar{V} + PbCl$

Hexagonal P 78° 46 Forms ∞P 0P (*o*), P (*z*), 2P, $\frac{1}{2}P$ ($b\frac{1}{2}$), $\infty P2$, $\infty P\frac{3}{2}$ 2P2 (fig 445) Transparent to opaque resinous Honey yellow to greyish brown streak white H = 3 G = 6 8 to 7 2 C c oxide of lead 70 83 vanadic acid 19 35 lead 7 2, chlorine 2 62 Wanlockhead, Windischkappel in Carinthia, Haldenwirthshaus in the Black Forest, Bolet in West Gotland, Berezovsk, Zimapan in Mexico Cordoba in the Argentine Republic

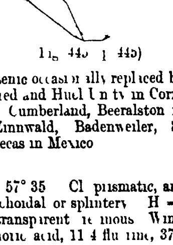


Fig 445 (sp 445)

446 Mimetesite, $3Pb_3\dot{As} + PbCl$

Hexagonal, P 81° 48 Crystals ∞P, 0P P (figs 91, 444), or P, 0P Cl P, fracture conchoidal or uneven H = 3 5 to 4 G = 7 19 to 7 25 Translucent Colourless but usually honey or wax yellow yellowish green or grey C c 90 7 arseniate and 9 3 chloride of lead but part of the arsenic occasionally replaced by phosphoric acid Leadhills Huel Alfred and Huel Unity in Cornwall, Roughten Gill and Dry Gill in Cumberland, Beeralston in Devonshire, Johann Georgenstadt Zinnwald, Badenweiler, St Prix in France, Nertchinsk and Zacatecas in Mexico

447 Wagnerite, $Mg_3\bar{P} + MgF$

Oblique prismatic C 63° 25 ∞P 57° 35 Cl prismatic, and orthodiagonal imperfect fracture conchoidal or splintery H = 5 to 5 5 G = 3 to 3 2 Translucent or transparent resinous Wine yellow and white C c 43 3 phosphoric acid, 11 4 fluorine, 37 6 magnesia and 7 7 magnesium but with 3 to 4 5 iron protoxide and 1 to 4 lime Werfen in Salzburg

448 Triplite, $(Fe, Mn)_3\bar{P} + RF$

Oblique prismatic, only granular Cl in two directions at right angles, fracture conchoidal H = 5 to 5 5 G = 3 6 to 3 8 Translucent or opaque, resinous Chestnut or blackish brown, streak yellowish grey C c iron and manganese protoxides, with 33 phosphoric acid, and 7 or 8 fluorine. Limoges, Schlaggenwald.

449 **Zwieselite**, $(\mathrm{Fe}, \mathrm{Mn})_3\mathrm{P} + \mathrm{FeF}$

Right prismatic, but only massive Cl basal, perfect H = 4 5 to 5, G = 3 95 to 4 Brown, streak yellow C c like triplite Zwiesel in Bavaria

450 **Amblygonite** $\overline{\mathrm{Al}}_3\mathrm{P}_3 + (\mathrm{Li}, \mathrm{Na})_3\mathrm{P}_3 + \overline{\mathrm{Al}}\mathrm{F}_3 + (\mathrm{Li}, \mathrm{Na})\mathrm{F}$

Anorthic crystals rare coarse granular Cl 0P, pearly, meeting two others at 105° and 87° 40 Fracture uneven and splintery H = 6 G = 3 to 3 1 Translucent, vitreous Greyish or greenish white to pale mountain green C c 47 9 phosphoric acid, 34 5 alumina 6 9 lithia, 6 soda, and 8 3 fluorine Penig, Arendal, Montebras (Creuse, France), also Hebron and Paris in Maine *Montebrasite* has no soda

451 **Durangite**, $(\mathrm{R}_2)\,\overline{\mathrm{As}} + 2\mathrm{NaF}$

Oblique prismatic, crystals like keilhauite (sp 669) ∞P 110° 10, P 112° 10 Cl prismatic H = 5, G = 3 95 to 4 Bright orange-red, streak cream yellow Vitreous C c alumina 17 2, iron protoxide 9 2, arsenic acid 53, soda 13 1, fluorine 7 7 Durango (Mexico)

452 **Herderite**

Right prismatic P polar edges 77° 20 and 141° 16, ∞P̆ 115° 53 Fracture conchoidal H = 5, G = 2 9 to 3 Translucent, vitreous, inclining to resinous Yellowish or greenish white Ehrenfriedersdorf in Saxony An anhydrous phosphate of alumina with lime and fluorine

Phosphates with Sulphates and Borates

453 **Svanbergite**

Rhombohedral, R 90° 35 H = 4 5 G = 2 57 Vitreous to adamantine Honey yellow, reddish brown, and rose red, streak reddish Subtransparent C c 37 8 alumina, 6 lime, 17 3 sulphuric acid, 12 8 soda, 17 8 phosphoric acid, 6 8 water Horrsjoberg in Wermland

454 **Diadochite**, $\overline{\mathrm{Fe}}_2\mathrm{P}_2 + 2\overline{\mathrm{Fe}}\mathrm{S}_2 + 32\overline{\mathrm{H}}$

Reniform and stalactitic, fracture conchoidal H = 3, G = 1 9 to 2 Resinous, vitreous Yellow or yellowish brown, streak white C c 36 7 iron protoxide, 14 8 phosphoric acid, 15 2 sulphuric acid, and 30 3 water Grafenthal and Saalfeld

455 **Pitticite**, $\overline{\mathrm{Fe}}_2\mathrm{S}_3 + 2\overline{\mathrm{Fe}}\mathrm{As} + 24\overline{\mathrm{H}}$

Reniform and stalactitic, brittle, fracture conchoidal H = 2 3, G = 2 3 to 2 5 Translucent throughout, or on the edges, resinous to vitreous Yellowish, reddish, or blackish brown, sometimes in spots or stripes streak light yellow or white C c 35 iron peroxide, 26 arsenic acid, 14 sulphuric acid, and 24 water In many old mines, as Freiberg and Schneeberg.

456 **Beudantite**

Rhombohedral, R 91° 18 H = 3 5 G = 4 Vitreous Olive green streak greenish yellow C c oxide of iron 40 69, oxide of lead 24 05, sulphuric acid 13 76, phosphoric acid 8 97, water 9 77 Dernbach in Nassau, Cork in Ireland

457 **Luneburgite** $(2\mathrm{Mg}, \overline{\mathrm{H}})\,\mathrm{P} + \mathrm{Mg}_2\overline{\mathrm{B}} + 7\overline{\mathrm{H}}$

Concretions of fibrous structure C c 25 2 magnesia, 29 83 phosphoric acid, 14 74 boracic acid, 30 23 water Luneburg

ARSENITES

458 **Ecdemite**, $\mathrm{Pb}_3\mathrm{As}_2 + 2\mathrm{PbCl}_2$

Pyramidal Cl 0P H = 2 5 to 3, G = 7 14 Pale green Vitreous on cleavage, resinous on fracture C c oxide of lead 59 67, lead 22 2, arsenious acid 10 59, chlorine 7 58 Långban in Wermland

459 **Trippkeite**, $\mathrm{Cu}\overline{\mathrm{As}}$

Pyramidal, P 111° 56 Blue green Lustrous Copiapo in Chili

SILICATES

Andalusite Group

460 **Andalusite** $\overline{\mathrm{Al}}\mathrm{Si}$

Right prismatic ∞P (*m*) 90° 50′, P∞ (*r*) 109° 4, P∞ (*s*) 109° 51′

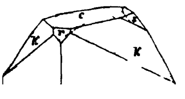


Fig 446

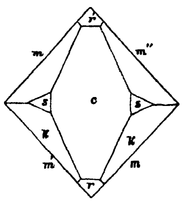


Fig 447

Also columnar Cl *m*, fracture splintery H = 7 to 7 5, G = 3 1 to 3 2 Pellucid, vitreous Grey, green, red, or blue B B infusible Not affected by acids C c alumina 63 1, silica 36 9 Clashnaree (figs 446 to 449) and Clova in Aberdeenshire, Marnoch and Botriphnie in Banffshire, Killiney Bay in Wicklow, Andalusia, Tyrol, Penig, Massachusetts, Litchfield in Connecticut

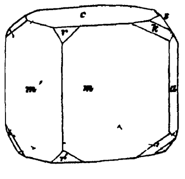


Fig 448

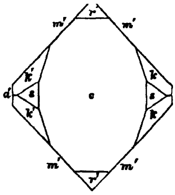


Fig 449

Chiastolite H = 5 to 5 5, G = 3 Pale grey, yellow, green, and red A compound structure, formed of four double wedge shaped crystals, arranged in contact with the angles of a square conoidal crystal placed in their centre, and imbedded in a paste of clay slate The section of the compound structure forms a tesselated cross, the appearance of which varies with the portion of the crystal which is cut Portsoy (fig 450) and Boharm in Banffshire, Wicklow, Keswick and Skiddaw, Brittany, Pyrenees, Maine, New Hampshire, Nova Scotia, Canada

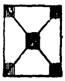


Fig 450

461 **Cyanite** (*Disthene*), $\overline{\mathrm{Al}}\mathrm{Si}$

Anorthic, generally broad prismatic lengthened crystals, formed by two faces (*m*, *t*) *m* *t* 106° 15, *m* *l* 145° 41, *p* *m* 93° 15 (fig 451) Hemitropes common, united by *m* Also radiated Cl *m*, perfect, brittle H = 7, on cl planes 5, G = 3 5 to 3 7 Pellucid, vitreous Cl pearly Colourless, and red, yellow, green, grey, and blue B B infusible Not affected by acids C c same as andalusite Hillswick in Shetland, Mount Battock, Tarfside (fig 451), Botriphnie (Banffshire), Tyrol, St Gotthard, Bohemia, Pontivy in France

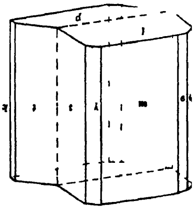


Fig 451

462 **Sillimanite**, $\overline{\mathrm{Al}}\mathrm{Si}$

Right prismatic, ∞P 111° Crystals fibrous, columnar, and radiating Cl macrodiagonal H = 7, G = 3 2 to 3 26 Translucent, resinous, on cl vitreous Greyish, greenish, clove, or hair-brown C c and chemical characters like cyanite Tvedestrand, Norway, Chester and Norwich, Connecticut $\mathrm{Al_2O_3, SiO_2}$ is thus trimorphous

Monrolite, *Xenolite*, *Bucholzite*, *Fibrolite*, and *Bamlite* are varieties

463 **Topaz**, $5\overline{\mathrm{Al}}\mathrm{Si} + \overline{\mathrm{Al}}\mathrm{F}_3 + \mathrm{SiF}_2$

Right prismatic ∞P (*M*) 124° 17′, 2P̆∞ (*n*) 92° 42′, ∞P̆2 (*l*) 93° 14′, P (*o*) Crystals always prismatic (fig 122), often hemimorphic Cl basal, perfect, fracture conchoidal H = 8, G = 3 4 to 3 6 Transparent, vitreous Colourless, honey yellow, amber, pink, asparagus green, blue Becomes electric by heat or friction, and the yellow colours become pink B B infusible Not affected by h acid, by digestion in s acid gives traces of fluorine The formula requires 33 2 silica, 56 7 alumina, 17 5 fluorine Part of the oxygen must be replaced by fluorine, as the total of the above is 107 4 Ben-a-bourd and Arran, Scotland, Mourne Mountains, Ireland, St Michael's Mount, Cornwall, Siberia, Saxony, Bohemia, Connecticut, Australia, Ceylon, Brazil, Peru The finest topazes are the blue from Scotland and Siberia, the pink, the yellow from Brazil, and the colourless from Peru The last named when cut may be distinguished at once from diamond by their electricity *Pyrophysalite* is a massive opaque cleavable variety from Falun *Pycnite* is a columnar straw-yellow to reddish white variety from Zinnwald in Saxony and Durango in Mexico

464 **Staurolite**, $(\overline{\mathrm{Al}}, \overline{\mathrm{Fe}})\,\mathrm{Si} + (\mathrm{Fe}, \mathrm{Mg})\,\mathrm{Si}$

Right prismatic ∞P (*m*) 128° 42′, P̄∞ (*r*) 70° 46′, ∞P̄∞ (*o*), 0P̆ (*p*) (fig 452) Twins common, as figs 140, 144, 187, 453 Cl brachydiagonal, perfect, fracture conchoidal to splintery H = 7, G = 3 5 to 3 8 Transparent to opaque, vitreous to resinous Reddish brown, streak white B B infusible Not affected by h acid, partially by s acid.

Fig 452 (Sp 464)

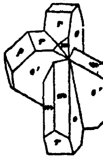


Fig 453.

C c silica 30, alumina 48 5, with 5 5 iron peroxide, 12 5 iron protoxide, 3 5 magnesia, often impure Bixeter Voe and Unst in Shetland, Boharm and Marnoch in Banffshire, St Gotthard, Greiner in Tyrol, Finisterre, Urals, and North America *Xantholite* is a yellow variety from Urquhart (Inverness)

465 **Sapphirite**, 4Mg, 5Al, 2Si

Oblique prismatic, granular H = 7 to 8 G = 3 4 to 3 5 Vitreous, pale blue or green, translucent, dichroic C c alumina 63 2, magnesia 19 3, silica 14 9 Fiskenaes in Greenland

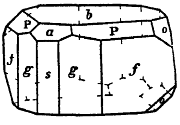
Tourmaline Group

466 **Tourmaline**, $R_3Si + RSi$

Rhombohedral, R 133 10 Crystals of 0R (*k*) − ½R, usually long prismatic, and striated (fig 45, and 249 to 252) Generally hemimorphic, also radiating and fibrous, fracture conchoidal to uneven H = 6 5 to 7 5, G = 3 to 3 3 Black varieties opaque, others transparent, vitreous Generally black, but colourless yellow, brown, blue, green, and rose red, streak white Different colours often disposed in layers parallel to the axis, and portions of one crystal differing also in colour along the axis By friction acquires positive electricity, and becomes electrically polar when heated Powder insol in h acid, imperfectly in s acid C c complex, but all with water and fluorine, some with boracic acid Coarse black columnar varieties, called *Schorl* very common in granite and gneiss Black occur at Portsoy in Banff, Clova, Cabrach, and Rubislaw in Aberdeenshire, Bovey in Devonshire, St Just in Cornwall, in Greenland, Arendal, Tyrol, and North America, blue or *Indicolite* at Uto in Sweden, green at Glen Skiag in Cromarty Crystals ruby red within surrounded by green or red at one extremity and green at the other, also blue and pink at Albany, Paris, and Hebron in Maine Crimson red or *Rubellite* in India and Ceylon, also in Siberia and Brazil

467 **Datholite**, $CaB + CaSi_2 + H$

Oblique prismatic, C 89° 51 ∞P (*g*) 115° 22 ∞P°2 (*f*) 76° 38, P (*P*) 120°, P°∞ (*a*) 45° 8, ∞P°∞ (*s*), 2P°∞ (*o*) (fig 454), or rhombic with *b* *f* 90°, *b* *a* 135°, *b* *c* 141° 9 and *f* *g* 160° 39 Fracture uneven or conchoidal H = 5 to 5 5 G = 2 9 to 3 Transparent or translucent vitreous Colourless and tinted greenish, yellowish, or pink In closed tube yields water B B intumesces and melts easily to a clear glass, colouring the flame green the powder gelatinizes in h acid C c 38 1 silica, 21 6 boracic acid, 34 7 lime, and 5 6 water Bishopton in Renfrew, Glen Farg in Perthshire (fig 455), Salisbury Crags and Corstorphine Hill near Edinburgh, Arendal, Uto, Andreasberg, Seisser Alp, Connecticut, and New Jersey Figs 238 239 are pseudomorphs of quartz after datholite termed *Haytorite*



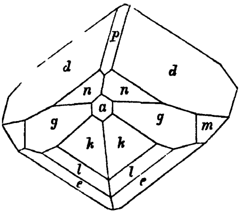


Fig 455 (sp 467)

468 **Euclase**, 2GlSi + AlH

Oblique prismatic, C 79° 44 ∞P°2 (*s*) 115°, 3P°3 (*f*) 105° 49′ Crystals specially of ∞P°2, ∞P°∞ (*T*), 3P°3 Cl clinodiagonal, perfect, very brittle and fragile fracture conchoidal H = 7 5, G = 3 to 3 1 Transparent splendent, vitreous. Mountain green, passing into blue, yellow, or colourless B B intumesces, becomes white, and melts in thin splinters to a white enamel Not affected by acids C c 42 silica, 35 alumina, 18 glucina, 6 water Peru and Brazil, and Southern Urals Cannot be used as a gem on account of its brittleness, whence its name

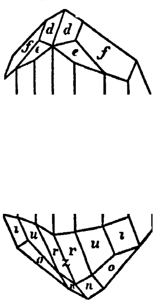


Fig 456.

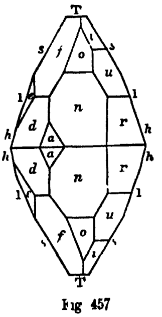


Fig 457

469 **Homilite**

Oblique prismatic, C 89° 21 H = 5 5, G = 3 28 Black and brownish black Vitreous C c 27 28 lime, 16 25 protoxide of iron, 31 87 silica, 18 1 boracic acid Stoko and Brevig (Norway)

470 **Botryolite**

Fine fibrous, botryoidal, or reniform Snow white to hair brown. Chemical and physical characters like datholite, but 10 64 of water,—being 2 equivalents Arendal

471 **Gadolinite**, (Y, Ce, Fe) Si

Oblique prismatic, C 89° 28 ∞P 116°, P 120° 56 (fig 458) Fracture conchoidal, or splintery H = 6 5 to 7, G = 4 to 4 4 Translucent on the edges, vitreous to resinous Black streak greenish grey B B the conchoidal (vitreous) varieties incandesce, gelatinizes in h acid C c 36 to 51 yttria, 10 to 15 iron protoxide 5 to 17 protoxide of cerium with lanthanum 0 to 12 glucina, and 25 to 29 silica Hittero in Norway, Ytterby, Broddbo and Finbo near Falun

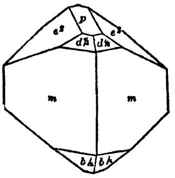


Fig 458 (sp 471)

Epidote Group

472 **Zoisite**, 4Ca, 3Al, 6Si + H

Right prismatic ∞P 116° 26, ∞P̄2 145 24, ∞P̄3 156° 40, P̄∞ 122° 4 2P̆∞ 111 6 (fig 459) Cl brachydiagonal perfect H = 6 G = 3 2 to 3 4 White, brownish grey, and dark green B B intumesces, and forms a white or yellow porous mass and on the edges fuses to a clear glass C c 29 8 alumina, 24 35 lime, 2 8 oxide of iron, 40 3 silica and 2 1 water Glen Urquhart Dalnain and Allt Gonolan Inverness Sterzing in Tyrol the Sau Alp in Carinthia, the Urals, and Connecticut *Thulite*, peachblossom red from Souland in Thelemark (Norway), is similar

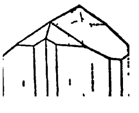


Fig 459 (sp 472)

473 **Epidote**, 4Ca, 3Al, 6Si + H

Oblique prismatic, C 89° 27 ∞P°∞ (*M*), ∞P 2 (*o*) 63° 1, P°∞ (*T*) 64° 36, − P (*n*) 70° 25, − P̄∞ (*r*) 63° 42′, P (*z*) 70° Crystals complex, with many partial forms Hemitropes united by *T*, also columnar and granular Cl *M*, perfect, also *T*, forming 115° 24, fracture conchoidal to splintery H = 6 to 7 G = 3 2 to 3 5 Pellucid, vitreous Green to yellowish grey B B fuses and swells to a dark brown slag, after fusion soluble with gelatinization in h acid C c 27 4 alumina, 8 5 iron peroxide, 23 9 lime, 38 3 silica 1 9 water Shetland Glenelg in Inverness, Tilquilly in Aberdeen in gneiss, in amygdaloid in Mull and Skye, in granite at Cassencary in Kirkcudbright, Arendal, Dauphine, Greenland, the Urals North America. *Withamite* from Glencoe is a red, strongly dichroic variety *Piedmontite* or *Manganese Epidote* brownish violet, from St Marcel, has 20 per cent of manganese peroxide

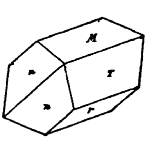


Fig 460

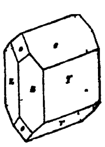


Fig 461

474 **Allanite** (*Orthite*, *Cerine*), $R_3Si + RSi$

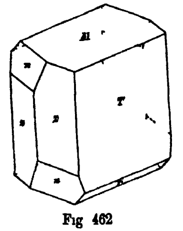


Fig 462

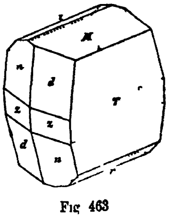


Fig 463

Oblique prismatic, C 65° ∞P (*z*) 70° 48 P (*n*) 71° 27, − P (*d*)

96° 40′, 0P (*M*), $\bar{P}\infty$ (*r*) $\infty P\infty$ (*T*) *M* *T* 115°, *T* *n* 111° 21′, *T* *d* 130° 18 Often massive or granular fracture conchoidal H = 6, G = 3 4 to 3 8 Translucent on edges, vitreous to resinous Black to brown or greenish, streak brownish grey B B froths and melts to a brown glass Gelatinous with h acid. C c 12 to 18 alumina with peroxide of iron, 13 to 26 oxide of cerium and lanthanum, 2 to 12 yttria 4 to 20 protoxide of iron, 30 of silica Small crystals common in the syenitic granites of Scotland, as at Lairg, Boat of Garten (fig 463), Aboyne, and Criffel In lime stone at Urquhart (fig 462), Greenland, Hittero and Snarum, Thuringia, Pennsylvania, New Jersey *Orthite* (massive) at Finbo, Kragero, and Falun *Cerine* (granular) at Riddarhyttan *Pyrorthite* has carbonaceous matter *Bodenite* is a variety

475 IDOCRASE, $3(Ca, Mg)_3Si + 2\bar{Al}Si$

Pyramidal, P (*c*) 74° 27′ (figs 464 to 466) Crystals ∞P (*d*), $\infty P\infty$ (*M*) P (*c*), 0P (*p*), $P\infty$ (*o*) 56° 29, $\infty P2$ (*f*) Prismatic, striated, also granular, fracture uneven H = 6 5, G = 3 35 to 4 Pellucid, vitreous to resinous Brown, green, yellow, streak white B B fuses easily, with intumescence, to a green or brown glass Partially sol in h acid, after ignition totally, gelatinizing C c alumina 16, peroxide of iron 7, lime 34, silica 38 Glen Gairn and Crathie, Aberdeenshire, in limestone, Broadford, Skye, Wicklow and Donegal, Ireland, Egg, Norway, Mussa, Piedmont, Vesuvius, Fig 466 Wilui river, near Lake Baikal (fig 463) *Cyprine* from Thelemark is azure blue, from copper

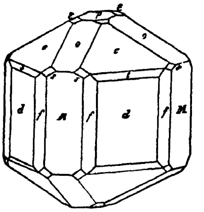


Fig 464

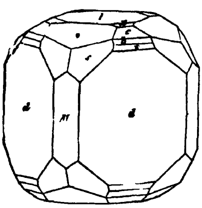


Fig 465

OLIVINE GROUP

476 FORSTERITE, Mg_2Si

Right prismatic Like olivine (sp 478) H = 6 to 7, G = 3 2 to 3 3 Vitreous, transparent White, wax yellow, greenish, streak white C c magnesia 57 1, silica 42 86 Vesuvius *Boltonite*, red, is from Massachusetts

477 FAYALITE, Fe_2Si

Right prismatic, *n* *n* 49° 36 (fig 467) Massive Cl rectangular Black, greenish, or brownish Metallic to resinous fracture conchoidal, magnetic H = 6 5, G = 4 to 4 1 C c protoxide of iron 70 5, silica 29 5 Mourne Mountains, Ireland, Fayal, Azores

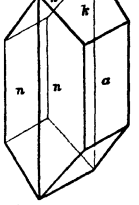


Fig 467 (sp 477)

478 CHRYSOLITE (*Olivine*, *Peridote*) $(Fe, Mg)_2Si$

Right prismatic P (*e*) 85° 16 and 139° 54, middle 108° 30 ∞P (*n*) 130° 2, $\bar{P}\infty$ (*d*) 76° 54, $2\breve{P}\infty$ (*k*) 80° 53 $\infty\bar{P}\infty$ (*M*) (fig 468) Also massive Cl brachydiagonal, perfect, fracture conchoidal H = 6 5 to 7, G = 3 3 to 3 5 Transparent, vitreous Olive green, yellow, brown, and colourless B B infusible Soluble, with gelatinizing in acids C c 47 magnesia 12 protoxide of iron, 40 silica. Talisker in Skye Haalival in Rum, Elie in Fife, Unkel on the Rhine, Vesuvius, Esneh in Egypt, Brazil *Hyalosiderite*, brown and yellow, with metallic lustre and 30 per cent protoxide of iron, is from the Kaiserstuhl in the Breisgau

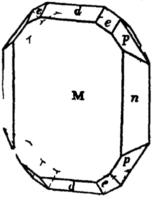


Fig 468 (sp 478)

479. TEPHROITE, Mn_2Si

Right prismatic granular, with rectangular cleavages Ash grey, rose-red. Adamantine, translucent H = 5 5 to 6, G = 4 to 4 1 C c. protoxide of manganese 70 2, silica 29 8 Franklin and Sparta in New Jersey

480 KNEBELLITE, $\dot{Fe}_2Si + \dot{Mn}_2Si$.

Massive Grey, brown, green, black Glistening; brittle. H = 6 5, G = 3 71 C c protoxide of iron 35 5, protoxide of manganese 35, silica 29 5 Ilmenau, Dannemora in Sweden

481 MONTICELLITE, $\dot{Ca}_2Si + Mg_2Si$

Right prismatic P (*f*) 110° 43′ and 97° 55, ∞P (*s*) 98° 7, $\infty\bar{P}2$ (*n*) 133° 6, $\breve{P}\infty$ (*k*) 81° 57, $\frac{1}{2}\breve{P}\infty$ (*h*) 120° 8, $\bar{P}2$ (*e*) 141° 47′ and 82°, $\infty\breve{P}\infty$ (*b*) (fig 469) Vitreous Grey, yellowish and greenish, and white, streak white Translucent H = 5 to 5 5, G = 3 to 3 25 C c lime 35, magnesia 21 9, protoxide of iron 5 6, silica 37 5 Sol in h acid, gelatinizing Somma (Milan)

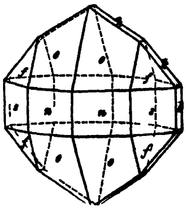


Fig 469 (sp 481).

482 CHONDRODITE (*Humite*), Mg_5Si_2

Right prismatic P middle edge 156° 38, polar edges 131° 34′ and 54° 28′ (figs 470 to 472) Crystals monoclinic in habit, often granular massive H = 6 5, G = 3 15 to 3 25 Translucent, vitreous to resinous Yellow, red, brown, green, and black, streak white B B infusible Decomposed by acids C c. silicate of magnesia, with 2 to 3 of fluorine From limestone on Loch Ness (?), Pargas, Finland, Gallsjo and Aker, Sweden, New York, Sparta, New Jersey *Humite*, from Somma

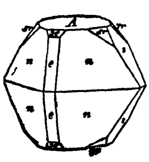


Fig 470.

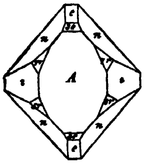


Fig 471

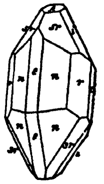


Fig 472

483 LIEVRITE, $3(Fe, Ca)_2Si + \bar{Fe}Si + \bar{H}$

Right prismatic P (*o*) polar edges 139° 30 and 117° 27′, ∞P 112° 38, $\bar{P}\infty$ (*d*) 112° 49, $\infty P2$ (*s*) 106° 15′ Crystals (fig 124) are long prismatic and vertically striated, also radiated, columnar, or fibrous, brittle H = 5 5 to 6, G = 3 9 to 4 2 Opaque, resinous or imperfect metallic Brownish or greenish black, streak black B B fuses easily to a black magnetic globule Sol in h acid, forming a yellow jelly C c 29 3 silica, 19 6 iron peroxide, 35 2 iron protoxide, 13 7 lime, and 2 2 water Rio in Elba, Fossum, Kupferberg, Rhode Island, and Greenland

484 CERITE $(Ce, R)_2Si + \bar{H}$

Hexagonal, 0P, ∞P, in low six sided prisms Generally fine-granular, fracture uneven, splintery, brittle H = 5 5, G = 4 9 to 5 Translucent on the edges, dull, adamantine, or resinous Clove brown, cherry red, or pearl grey Sol in h acid, leaving gelatinous silica. C c 20 5 silica, 73 5 protoxide of cerium (with didymium and lanthanum), and 6 water Bastnaes near Riddarhyttan

485 GALMEI, $Zn_2Si + \dot{\bar{H}}$

Right prismatic, and hemimorphic, $2\breve{P}2$ (*P*) with polar edges 101° 35′ and 132° 26′, ∞P (*d*) 103° 50, $\bar{P}\infty$ (*o*) 117° 14, $\breve{P}\infty$ (*l*) 128° 55′ (fig 46), common form $\infty\breve{P}\infty$ (*s*), ∞P, $\bar{P}\infty$ Also columnar, fibrous, granular, and earthy Cl prismatic along ∞P, very perfect, along $\bar{P}\infty$ perfect H = 5, G = 3 3 to 3 5 Transparent to translucent, vitreous and pearly Colourless or white, but often light grey, also yellow, green, brown, and blue, becomes electric by heat B B decrepitates slightly but is infusible, with cobalt solution blue and partly green, readily soluble in acids, and gelatinizes C c 25 silica, 67 5 zinc oxide, and 7 5 water Wanlockhead, Mendip Hills, Matlock, Raibl and Bleiberg in Carinthia, Aix la Chapelle, Iserlohn, Nertchinsk, Pennsylvania, Virginia. Used as an ore of zinc

WILLEMITE GROUP

486 WILLEMITE, Zn_2Si

Rhombohedral, R 116° 1 Cl basal, and prismatic, ∞R; brittle H = 5 5, G = 3 9 to 4·2 White, yellow, brown, and red. Vitreous lustre C c oxide of zinc 73, silica 27 Altenberg, Liege, Greenland, New Jersey

487 TROOSTITE, $Zn\dot{S}i + Mn\ddot{S}i$

Rhombohedral, R 116° Cl prismatic, ∞P2, brittle H = 5 5, G = 4 1 [illegible] green grey, and reddish brown Vitreous C c oxide of zinc oxide of manganese 13, silica 28 New Jersey

488 CENTROLITE (PbMn) Si

Right prismatic, ∞P 115° 18′ Form ∞P, P, ∞P̆∞ H = 5, G = 6 2 Red brown Cl prismatic, splendent on P Southern Chili

489 PHENACITE, Gl_2Si

Hexagonal and tetartohedral, R (*p*) 116° 36 (fig 473) Crystals R, ∞P2, $\frac{4}{3}$P2 Twins with parallel axes, and intersecting Cl R, and ∞P2, fracture conchoidal H = 7 5 to 8, G = 2 97 Transparent or translucent, vitreous Colourless, and wine yellow or brown when fresh, but colour soon lost on exposure B B infusible, not affected by acids C c glucina 45 8, silica 54 2 Framont in Alsace, Takovaya in Urals, Miask, Durango in Mexico

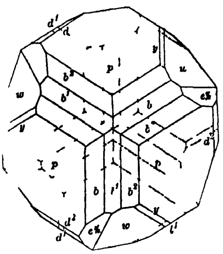


Fig 473 (sp 489)

490 DIOPTASE, CuSi + Ħ

Hexagonal and rhombohedral R 125° 54, −2R (*r*) 95° 28, ∞P2, −2R$\frac{7}{5}$ (*s*) (fig 474) Cl R, perfect, brittle H = 5, G = 3 2 to 3 3 Transparent or translucent, vitreous Emerald green, rarely verdigris green or blackish green, streak green C c 38 7 silica, 50 copper protoxide and 11 3 water Altyn Tubeh in the Kirghiz Steppe, Muroshnaya, Copiapo

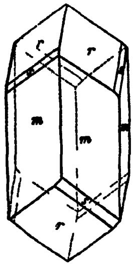


Fig 474 (sp 490)

491 CHRYSOCOLLA, CuSi + 2Ħ

Botryoidal or investing brittle, fracture conchoidal H = 2 to 3 G = 2 to 2 3 Translucent resinous Verdigris to emerald green or azure blue streak greenish white C c 34 83 silica, 44 94 copper protoxide, and 20 23 water Leadhills, Lackentyre in Kirkcudbright Cornwall, Saxony, Hungary, Spain, Urals, Australia, Chili

492 BOGOSLOVSKITE (*Kupferblau*)

Massive fracture conchoidal, brittle H = 4 to 5, G = 2 56 Sky to ultramarine blue streak smalt blue, and shining A silicate of copper, with 45 5 per cent copper oxide Schapbach Valley in Baden, Bogoslovsk in the Urals *Demidowite* may be the same

GARNET GROUP

493 GARNET, $R_3Si_2 + \bar{R}Si$

Cubic most common forms ∞O and 2O2 (figs 33 40, 60, 475) Also granular Cl dodecahedral, fracture conchoidal, or splintery H = 6 5 to 7 5, G = 3 5 to 4 3 Pellucid, vitreous or resinous Rarely colourless or white, generally red, brown, black green, or yellow B B in general fuses to a glass, black or grey in those containing much iron, green or brown in the others and often magnetic, imperfectly soluble in h acid C c exceedingly variable, but generally forming two series, according as R_2O_3 is chiefly alumina or chiefly iron peroxide, and these are again divided according as RO is more especially lime, iron protoxide, magnesia, or a similar base The more important varieties are—

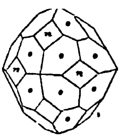


Fig 475

(1) *Lime Alumina Garnet*, $Ca_3Si_2 + \dot{A}lSi$, with 40 silica, 23 alumina and 37 lime To this subdivision belong—

(*a*) *Water Garnet* —Colourless to white Craig Mohr, Aberdeen, Thelemark in Norway

(*b*) *Grossular* —Olive to gooseberry green Craig Mohr, Wilui river, America

(*c*) *Cinnamon Stone* —Hyacinth red to orange yellow Glen Cairn (Aberdeen), Allt Gonolan and Ord Ban (Inverness), Ceylon, Wermland *Romanzowite*, from Kimito (Finland), is the same This variety when polished is often sold as *Hyacinth*

(*d*) *Common Lime Garnet* —Here one half of the alumina is replaced by iron peroxide Colours red, brown, yellow Piedmont, Vesuvius, the Urals

(2) ***Magnesia Alumina Garnet***, RO chiefly magnesia. Arendal

(3) *Manganese Alumina Garnet*, RO = MnO, reddish brown. Spessart (Bavaria), Sweden

(4) *Magnesia Iron Lime Alumina Garnet*, *Pyrope* — Colour port wine to purplish red Elie in Fife, Zoblitz in Saxony, Bohemia

(5) *Iron Alumina Garnet, Almandine, Noble Garnet* —Colombine red, inclining to violet, blood red, and reddish brown Common in mica slate, gneiss, and granite Shetland, Ross, Inverness, Aberdeen, Falun, Arendal, Tyrol, the Urals, North America, Pegu, and Ceylon

(6) *Lime Chrome Alumina Garnet*, $Ca_3Si_2 + (\bar{C}r, \dot{A}l)Si$, *Uwarowite* Emerald green, with 22 per cent chrome oxide Bisserak and Kyshtimsk in the Urals, India, and California

(7) *Lime and Iron Garnet*, $Ca_3Si_2 + \bar{F}e$, Si This includes—

(*a*) *Common Iron Garnet Rothoffite, Allochroite* —Subtranslucent or opaque Green, brown, yellow, or black, with white, grey, or yellow streak Sweden and Arendal

(*b*) *Melanite* —Black, opaque, in thin splinters translucent, streak grey, slightly magnetic Albano near Frascati, Vesuvius, France, Lappmark

(*c*) *Colophonite* —Yellowish brown to pitch black, also yellow or red, resinous, streak white G = 3 43 Arendal

The red varieties, when cut *en cabochon*, are termed *Carbuncles.*

494 AXINITE, ($\bar{A}l$, B) Si + 2(Ca, Fe)Si

Anorthic Crystals unsymmetrical *u P* 135° 31′, *u r* 115° 38, *P r* 134° 45 (figs 136, 137) Cl distinct along planes truncating the sharp edges between *P* and *u* and *P* and *r* H = 6 5 to 7, G = 3 2 to 3 3 Pellucid, vitreous Clove-brown, inclining to smoke grey or plum blue, but often cinnamon-brown in one direction dark violet blue in a second, and pale olive green in a third (*trichroism*) B B colours flame green intumesces, and fuses easily to a dark green glass, becoming black in the ox flame, not sol in h acid till after ignition, when it gelatinizes C c 45 9 silica, 5·9 boracic acid, 17 5 alumina, 9 3 iron (with manganese) protoxide, and 21 4 lime Botallack and other mines in Cornwall, Bourg d Oisans in Dauphine, Kongsberg, Arendal, Nordmark in Sweden, Pyrenees, St Gotthard, Tyrol, Thum in Saxony, Urals, and North America

495 DANBURITE (Ca, $\bar{B}$) 2Si

Right prismatic ∞P (*I*) 122° 52, ∞P̆2 (*e*) 94° 52, P̄∞ (*d*) 97° 7, 4P̆∞ (*w*) 54° 58, 0P (*c*), P (*o*), 2P̆2 (*r*) ∞P̄∞ (*a*), ∞P̆4 (*n*)

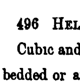


Fig 476

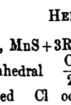


Fig 477

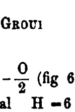


Fig 478

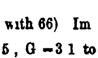


Fig 479

Cl basal, fracture uneven to subconchoidal, vitreous to greasy lustre H = 7 to 7 5, G = 2 986 to 3 021 Pale yellow to reddish brown Translucent, brittle C c 22 76 lime, 28 46 boracic acid, 48 76 silica Danbury in Connecticut, Russell in New York

HELVINE GROUP

496 HELVINE, MnS + $3R_2Si$

Cubic and tetrahedral $\frac{O}{2}$ or $\frac{O}{2} - \frac{O}{2}$ (fig 64 and with 66) Imbedded or attached Cl octahedral H = 6 to 6 5, G = 3 1 to 3 3 Translucent on the edges, resinous Wax yellow, siskin green, or yellowish brown B B in the red flame fuses with intumescence to a yellow obscure pearl, sol in h acid, evolving sulphuretted hydrogen, and gelatinizes C c 34 silica, 10 glucina, 8 iron protoxide, 43 manganese protoxide, and 5 sulphur. Schwarzenberg in Saxony, and near Modum in Norway

497 DANALITE, $3R_2\dot{S}i$ + ZnS

Cubic In octahedra, with striated dodecahedral planes. H = 5½ to 6, G = 3 43 Vitreous to resinous Flesh red to grey, streak lighter Translucent, brittle C c protoxide of iron 29, of manganese 6 5, of zinc 19, silica 31 5, sulphur 5 5 Rockport in Massachusetts

498 EULYTINE, $\bar{B}i_2Si_3$

Cubic and tetrahedral $\frac{2O2}{2}$ and $-\frac{2O2}{2}$ The crystals (fig 66) small, and often with curved faces, fracture conchoidal. H = 4 5 to 5, G = 5 9 to 6 1 Transparent and translucent, adamantine. Clove-brown, yellow, grey, or white, streak white or grey C c. 16 2 silica and 83 8 bismuth peroxide Schneeberg and Braunsdorf near Freiberg

SCAPOLITE GROUP.

499 **SARCOLITE**, $8\dot{C}a$, $3Al\,Na$, $9Si$

Pyramidal P 102° 54 , ∞P∞ 0P, P, and other faces as in fig 480, many of the faces being alternately hemihedral H = 5 5 to 6, G = 2 93 Vitreous Grey to rose red Translucent, very brittle C c alumina 21 5, lime 32 4, soda 3 3, silica 40 5 B B fuses to a white enamel, gelatinizes with acids Somma

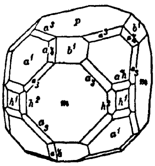


Fig 480 (sp 499)

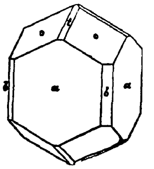


Fig 481 (sp 500)

500 **MEIONITE** $6(Ca, Na)$, $4Al$, $9Si$

Pyramidal P (*o*) 63° 42 , P∞ (*t*) ∞P (*a*) ∞P (*b*) (fig 481) Cl macrodiagonal H = 5 5 to 6 G = 2 6 to 2 74 Vitreous Colourless or white Transparent Much cracked C c 31 9 alumina, 26 2 lime, 41 9 silica Gelatinizes in acids Somma

501 **MIZZONITE**, $6(Ca, Na)$ $4Al$, $15Si$

Pyramidal P 64° 4 (fig 482) Similar to meionite C c alumina 23 8, lime 8 8 soda 9 8, silica 54 7 Insoluble in h acid Somma

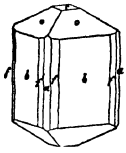


Fig 482 (sp 501)

502 **SCAPOLITE**, $3(Ca, Na)Si + Al\,Si_3$

Pyramidal P 63° 42 , ∞P∞ , P, ∞P , also massive Cl ∞P∞, perfect, and ∞P H = 5 to 5 5, G = 2 6 to 2 8 Transparent or translucent, vitreous, pearly, or resinous Colourless, but also pale grey, green yellow or red B B melts with effervescence to a vesicular glass, in the closed tube may show traces of fluorine, with solution of cobalt becomes blue Sol in h acid C c 49 silica, 28 alumina (with iron peroxide) and 23 lime (with soda) Tiree (Scotland), Arendal, Tunaberg, Pargas, Massachusetts, and New York Known by its rectangular cleavage, resinous lustre on fractured surfaces, and action B B *Dipyre*, P 64° 4, is a variety

503 **MELLILITE** (*Humboldtilite*) $2(Ca, Mg)Si_2 + (Al, Fe)Si$

Pyramidal P 65° 30 , 0P, ∞P∞ Cl basal, perfect H = 5 to 5 5, G = 2 91 to 2 95 Translucent on edges vitreous to resinous Honey yellow, orange brown, and yellowish white C c 32 lime, 7 magnesia, 9 alumina, 7 iron peroxide, 40 silica Capo di Bove, and Vesuvius

504 **GEHLENITE** $(Ca, Fe)_3Si + (Al, Fe)Si$

Pyramidal P 59° 0P ∞P∞ ∞P3, 2P Cl basal H = 5 5 to 6, G = 2 9 to 3 1 Translucent on edges Dull resinous Mountain, leek, or olive green, and liver brown C c 22 alumina, 5 iron peroxide, 35 lime, 4 magnesia, 31 4 silica Monzoni in the Fassa Valley

NEPHELINE GROUP

505 **LEUCITE**, Al, $Si_3 + KSi$

Pyramidal Combination of the ditetragonal pyramid (*i*) with the tetragonal pyramid (*o*), and 2P∞ (*u*) with ∞P(*m*) Hemitropes united by (*u*) Fracture conchoidal H = 5 5 to 6, G = 2 4 to 2 5 Transparent to translucent on the edges, vitreous inclining to resinous Colourless, but greyish, yellowish, or reddish white, streak white B B infusible, with cobalt solution becomes blue Sol in h acid, without gelatinizing C c 54 9 silica, 23 6 alumina, and 21 5 potash Abundant in the lavas of Vesuvius, the tufas near Rome, and the peperino of Albano, also at the Kaiserstuhl, and near Lake Laach Readily distinguished from analcime by its infusibility, and by never showing faces of the cube

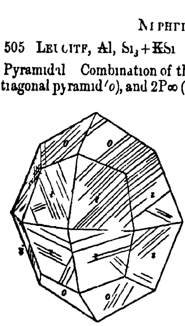


Fig 483

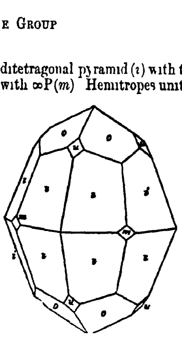


Fig 484

506 **NEPHELINE** (*Elæolite*), $AlSi + 4(Na, K)Si$.

Hexagonal P 88° 10 ∞P, 0P, P common; also fig 485 Crystals imbedded, or in druses, also massive granular, fracture conchoidal, or uneven H = 5 5 to 6, G = 2 58 to 2 64 Transparent or translucent, vitreous and resinous Colourless or white (nepheline), or opaque, dull resinous, and green, red, or brown (elæolite) B B melts difficultly (nepheline), or easily with slight effervescence (elæolite), into a vesicular glass Sol and gelatinizes in h acid C c 41 2 silica, 35 3 alumina, 17 soda, 6 5 potash Nepheline at Monte Somma, Capo di Bove, Katzenbuckel in the Odenwald, Aussig, and Lusatia Elæolite in the zircon syenite at Laurvig Frederiksvarn, Brevig, and Miask

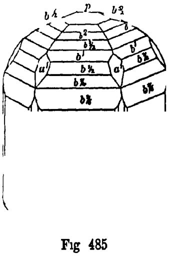


Fig 485

Davyne, with ½P 51° 16′, seems only a variety, as also *Cancrinite*, bright blue, and with some carbonate of lime

507 **MICROSOMMITE**, $RSi + AlSi + NaCl$

Hexagonal ∞P, 0P, ∞P2, ∞P$\frac{3}{2}$ Cl ∞P H = 6, G = 2 42 to 2 53 Colourless to yellow, lustre silky Somma and Vesuvius

508 **SODALITE**, $3(AlSi + NaSi) + NaCl$

Cubic, ∞O, and fig 486, generally distorted, also massive and granular Cl ∞O, fracture conchoidal or uneven H = 5 5, G = 2 13 to 2 29 Translucent vitreous White, grey, and rarely green or blue C c 37 silica, 31 8 alumina, 19 2 soda, 4 7 sodium, and 7 3 chlorine Greenland, Vesuvius, Ilmen Hills, Frederiksvarn, and Litchfield in Maine

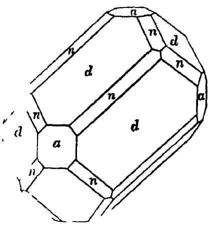


Fig 486 (sp 508)

509 **NOSEAN**, $3(AlSi + NaSi) + NaS$

Cubic, and granular H = 5 5, G = 2 28 to 2 40 Translucent, vitreous to resinous Ash or yellowish grey, sometimes blue, brown, or black C c 36 silica 31 alumina, 25 soda, and 8 sulphuric acid Lake Laach, and Rieden near Andernach. on the Rhine Occurs in phonolites, in minute crystals

510 **HAUYNE**, $2(AlSi + NaSi) + CaS$

Cubic, chiefly ∞O, also fig 487, but more common in grains Cl ∞O H = 5 to 5 5, G = 2 4 to 2 5 Semitransparent or translucent, vitreous or resinous Azure or sky blue, streak bluish white C c 34 2 silica, 28 5 alumina, 11 5 soda 4 3 potash, 10 4 lime, and 11 1 sulphuric acid Vesuvius, Mount Vultur near Melfi, the Campagna of Rome, and Niedermendig near Andernach

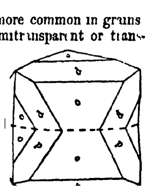


Fig 487 (sp 510)

511 **LAPIS LAZULI**

Cubic, O∞, generally massive, granular H = 5 5, G = 2 38 to 2 42 Translucent on edges, dull resinous or vitreous Ultramarine, or azure blue, streak light blue B B fuses readily to a white porous glass In h acid the powder is dissolved and gelatinizes, evolving sulphuretted hydrogen C c 45 50 silica, 5 89 sulphuric acid 31 76 alumina 9 09 soda, 3 52 lime, 0 86 iron, 0 42 chlorine, 0 95 sulphur, 0 12 water Near Lake Baikal, China, Tibet, Tartary, Monte Somma, and Chili It is used for ornamental purposes, and in the preparation of ultramarine The colour both in it and hauyne seems due to some compound of sulphur with sodium and iron

MICA GROUP

512 **BIOTITE** (*Magnesia Mica*), $Al_2Si_3 + (Mg, K, Fe)_3Si_2$.

Oblique prismatic, C 89° 59′ 0P (*c*), 98° 41′ P (*m*), −½P (*o*), ∞P∞ (*b*), P∞ (*r*), −$\frac{3}{2}$P3 (*z*) Cl basal, perfect, sectile, thin plates elastic H = 2 5 to 3, G = 2 85 to 2 9 Transparent, but often only in very thin plates Generally uniaxal, sometimes with divergence = 56°. Metallic, pearly Usually dark green, brown, or black, streak greenish grey or white B B difficultly fusible to a grey or black glass Completely sol in concentrated s acid, leaving white

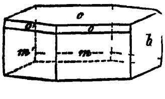


Fig 488

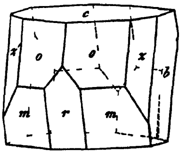


Fig 489

pearly plates of silica C c 39 silica, 17 alumina 10 iron protoxide, 20 magnesia, 9 potash Hillswick, Shetland, in gneiss Sutherland, Ross, Inverness, in limestone, Skye and Fife in trap Pargas Bodenmais, Greenland, New York *Rubellan* is a decomposed variety

513 HAUGHTONITE, $(\overline{Al}, \overline{Fe})\,Si + (Fe, K)\,Si$

Oblique prismatic Cl basal, perfect H = 3, G = 3 1 Vitreous to adamantine Chocolate brown to black Weathers pal green and ochry Difficultly soluble in acids B B fused with difficulty to a highly magnetic bead C c silica 36 alumina 18, ferric oxide 4 5, ferrous oxide 18, magnesia 9 potash 8 water 3 Common in the granites of Scotland Black Forest Harzburg, Tyrberger

514 LEPIDOMELANE, $(\overline{Al}, \overline{Fe})\,Si + (\dot{F}e, K)\,Si$

Oblique prismatic Cl basal, perfect, brittle *H* = 3 G = 2 97 Vitreous, transparent to opaque Rich brown to raven black B B fuses easily to a black feebly magnetic bead Sol in h acid, leaving pearly scales of silica C c 37 silica, 17 alumina 24 iron peroxide, 3 protoxide of iron, 8 potash, 10 magnesia, 4 water Rarely in gneiss, Scotland, common in granite, Ireland, and Persberg, Sweden

515 ANOMITE, $12\,Mg\;3\,\overline{Al},\;2\,K\;\dot{H},\;12\,Si$

Oblique prismatic *c m* 98° 42 Form *c*, *m*, *o*, *b* (see fig 488), divergence of optic axes 12 to 16° Monroe (New York), Lake Baikal

516 PHLOGOPITE, $(\tfrac{2}{3}R_3 + \tfrac{1}{3}\dot{R})\,Si_3$

Oblique prismatic 0P (*c*) P (*m*), $-\tfrac{1}{2}$P (*o*), ∞P∞ (*b*) *c m* 98° 30′ to 99° Cl basal, perfect H = 2 5 to 3, G = 2 75 to 2 97 Pearly to submetallic Yellowish brown with copper like reflexion, also green, white, and colourless Transparent Divergence of optic axes 3° to 20° C c 14 alumina, 2 protoxide of iron, 28 magnesia, 8 6 potash, 2 57 fluorine, 41 silica B B whitens, and fuses on edges Decomposed by s acid, leaving the silica in scales Pargas (Finland), Fassa Valley, New York, Canada Ceylon Characteristic of serpentine and of dolomitic limestones

517 ZINNWALDITE

Oblique prismatic Forms as in figs 490, 491, also $2\bar{P}\infty$ (*H*) and $3\breve{P}3$ (*x*) *m c* 98° to 99° Divergence of optic axes 65° G = 2 82 to 3 2 C c similar to muscovite (sp 519), but with 4 to

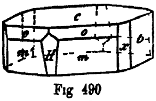


Fig 490

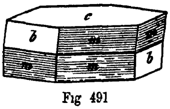


Fig 491

8 fluorine, 2 to 5 lithia, and traces of rubidium, cesium, and thallium Altenberg and Zinnwald, St Just and Trewavas in Cornwall *Cryophyllite* from Cape Ann in Massachusetts is similar

518 LEPIDOLITE

Oblique prismatic Forms like muscovite Divergence of optic axes 50° to 77°. Cl basal, perfect H = 2 5 to 4, G = 2 84 to 3 Often massive, scaly granular, coarse or fine Lustre pearly Colour rose-red, violet, lilac, yellow, greyish white Contains 5 to 6 per cent lithia, with rubidium, cæsium, and thallium, also fluorine B B colours flame red Mourne Mountains, Rozena (Moravia) Uto (Sweden), Ekaterinburg, Maine

519 MUSCOVITE (*Muscovy Glass*), $3\overline{Al}\,Si + \dot{K}\,Si$

Right prismatic, with monoclinic habit 0P (*c*) ∞P (*M*) $\infty\breve{P}\infty$ (*b*), P (*m*), $2\breve{P}\infty$ (*y*) ∞P nearly 120° Twin face *c* Cl basal, perfect, elastic Angle of optic divergence from 44° to 77° Metallic, pearly Colourless, and tinged of various shades to black B B fuses to an opaque enamel Not affected by acids C c 36 6 alumina, 11 8 potash, 45 1 silica, 4 5 water, with traces of fluorine Shetland Loch Glass in Sutherland, Glen Skiag (crystals 15 inches in length) and Struay Bridge in Ross, Aberdeen, Cornwall, St Gotthard, Norway, Sweden, Siberia Crystals over a yard in diameter in China, where it is used for windows *Fuchite* bright green, has 6 per cent of chrome oxide *Margarodite* contains 4 to 6 water *Gilbertite*, Cornwall, may be different

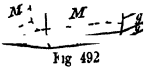


Fig 492

520 PARAGONITE (*Soda Mica*), $3\overline{Al}\,Si_3 + (\dot{N}a, \dot{H})\,Si$

Massive, foliated Lustre pearly H = 2 5 to 3, G = 2 78 to 2 9 Yellowish, greyish, and greenish C c 40 1 alumina, 6 1 soda, 47 75 silica, 4 6 water Monte Campione, St Gotthard

521 SANDBERGERITE (*Baryta Mica*)

White minute scaled aggregates G = 2 894 C c 30 2 alumina, 4 9 magnesia, 5 9 baryta 7 6 potash, 42 6 silica, 4 43 water Pfitsch Valley in Tyrol, and the Swiss Alps

522 MARGARITE (*Lime Mica*)

Right prismatic Cl basal perfect H = 3 5 to 4 5, G = 2 99 to 3 1 Lustre of cl pearly Lateral planes, vitreous Snow white, reddish white, and pearl grey Laminæ brittle Optic axial angle 109° to 129° C c 51 2 alumina 11 6 lime, 2 6 soda, 30 1 silica and 4 5 water Greiner in Tyrol, Naxos, Asia Minor, Greece, Pennsylvania, North Carolina *Diphanite* is similar.

523 EUPHYLLITE $(\tfrac{1}{3}\dot{R}_3 + \tfrac{2}{3}\overline{R})\,Si_3 + \tfrac{4}{3}\dot{H}$

Like muscovite, but laminæ not easily separable H = 3 5 to 4 5, G = 2 83 to 3 Lustre of cl pearly to adamantine White to colourless Transparent to opaque Laminæ brittle Optic axial angle 71½° C c alumina 42 3, lime 1 5, potash 3 2, soda 5 9, silica 41 6, water 5 5 Unionville in Pennsylvania

524 CLINTONITE, $(\tfrac{2}{3}R_3 + \tfrac{1}{3}\overline{Al})\,Si + \tfrac{1}{3}\dot{H}$

Oblique prismatic in hexagonal tables, or massive foliated Cl basal perfect H = 5 to 5 5, G = 3 15 Translucent, pearly to metallic on the cleavage Angle of the optic axes 3° to 13° Reddish brown to yellow C c 39 7 alumina, 21 1 magnesia, 13 1 lime, 19 2 silica, 2 protoxide of iron 4 9 water Amity and Warwick in New York *Brandisite* is similar

525 XANTHOPHYLLITE

Oblique prismatic, C about 90° Crystalline aggregates Radiate lamellar H = 4 5 to 6 G = 3 1 Lustre pearly Colour yellowish to copper red Angle of optic axes 0° to 20° C c alumina 43 6, lime 13, magnesia 17 5, silica 16 9, water 5 1 Zlatoust

526 CHLORITOID, $\dot{F}e\,Si + \overline{Al}\,\dot{H}$

Right prismatic in foliated crystals, brittle Cl basal Lustre greasy to pearly H = 5 5 to 6, G = 3 52 to 3 56 Dark green streak greenish white C c 40 alumina, 27 protoxide of iron 25 silica 7 water B B infusible, but becomes magnetic Decomposed by s acid Hillswick in Shetland, Pregratten in Tyrol, Ekaterinburg, Canada

527 MASONITE

Broad plates H = 6 5, G = 3 53 Grey green Streak grey Pearly to vitreous C c 26 4 alumina, 19 peroxide of iron, 16 7 protoxide of iron, 32 68 silica 4 5 water Middletown in Rhode Island

528 OTTRELITE $\overline{Al}\,Si_3 + 3(Fe, Mn)\,Si + 3\dot{H}$

Thin hexagonal tables Cl parallel to the prismatic faces H = 5 5, G = 4 4 Translucent, vitreous Greenish or blackish grey C c 24 3 alumina 16 8 protoxide of iron, 11 1 protoxide of manganese, 43 4 silica, 5 65 water Ottrez in the Ardennes (Luxemburg) Aste in the Pyrenees, Ebnat in Bavaria, Newport (Rhode Island), Vardhos (Greece)

529 PYROSMALITE, $7\dot{R}\,Si + R\,Cl + 5\dot{H}$

Hexagonal P 101° 34, crystals ∞P, 0P, tabular, also granular Cl basal perfect, brittle H = 4 to 4 5, G = 3 to 3 2 Translucent to opaque, resinous or metallic pearly Liver brown to olive green C c 35 5 silica 27 5 iron protoxide, 21 5 manganese protoxide, 8 chloride of iron or manganese, and 7 5 water Nordmark in Sweden

530 ASTROPHYLLITE, $(\dot{R}_3, \overline{R})\,Si_3$

Right prismatic, with oblique habit In long tabular prisms, and in stellate groups Cl basal, perfect H = 3 5, G = 3 33 Submetallic to pearly Tombac brown to gold-yellow Pellucid Axial divergence 118° to 124° C c peroxide of iron 9 3, protoxide 23 6, protoxide of manganese 10, soda 3 9, potash 5 9, titanic acid 7 90, silica 39 2 Brevig, El Paso in Colorado

CHLORITE GROUP

531 CHLORITE, $2\dot{R}\,Si + \dot{R}\,\overline{Al} + 3\dot{H}$

Hexagonal P 106° 50, crystals tabular of 0P, ∞P or 0P P (fig 493) often in comb like or other groups, generally foliated and scaly H = 1 to 1 5, G = 2 78 to 2 96 Leek green to blackish green streak greenish grey C c 21 alumina 20 protoxide of iron, magnesia 18 silica 24, water 11 Tarfside Bute, and Jura in Scotland Cornwall Cumberland, Wales, Fassa Valley, Urals, America

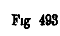


Fig 493

532 PENNINE, $4Mg\dot{S}i+Mg_3\bar{A}l+5\bar{H}$

Hexagonal, rhombohedral R 65° 28 Crystals chiefly very acute rhombohedrons, with or without the base Lustre resinous. H = 2 to 3, G = 2 6 to 2 77 Streak greenish white B B exfoliates, becomes white, and fuses on the edges to a white enamel Completely sol in warm s acid C c 33 6 silica, 14 4 alumina, 39 4 magnesia and 12 6 water, but with 5 to 6 iron protoxide replacing magnesia Scalpa in Harris, Glen Lochy in Perthshire Zermatt in Valais Tyrol Ala di Stura in Piedmont, Mauléon in the Pyrenees *Leuchtenbergite* is the same *Kammererite*, with 5 to 8 chromium sesquioxide, is violet blue or green, Unst, Siberia, Pennsylvania *Rhodochrome* and *Tabergite* are also varieties

533 CLINOCHLORE (*Ripidolite*), $3MgSi+Mg_3\bar{A}l+4\dot{\bar{H}}$

Oblique prismatic, C 76° 4 ∞P 121° 28 0P P 113° 59, 0P ∞P 192° 8 Crystals −2P, P, 4P∞, 0P (*n*, *m* *t*, P, fig 494) Twins common, lustre vitreous or resinous H = 2 to 3, G = 2 6 to 2 8 B B becomes white, and fuses on thin edges to a greyish yellow enamel C c 30 3 silica, 17 3 alumina 40 3 magnesia, and 12 1 water Edentian and Blair Athole in Scotland, Traversella in Piedmont, Akhmatovsk in Urals, West Chester in Pennsylvania *Corundophyllite*, *Epichlorite*, and *Kotschubeyite* are varieties

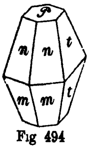


Fig 494

534 PYROSCLERITE ($\frac{2}{3}\dot{R}$, $\frac{1}{3}\bar{R})_3Si_3+3\dot{\bar{H}}$

Right prismatic Cl basal, perfect, fracture uneven, brittle, sectile H = 3, G = 2 7 to 2 8 Pearly, translucent Apple, emerald and grey green C c alumina 13 4, chrome oxide 1 4, protoxide of iron 3 5, magnesia 31 6, silica 37, water 11 Porto-Ferraio in Elba, China

535 CHONICRITE

Massive, crystalline granular and globular radiated H = 2 5 to 3 G = 2 91 Weak silky White, with yellowish spots, greenish blue C c 17 1 alumina, 22 6 magnesia, 12 6 lime, 35 7 silica, 9 water B B fuses easily, with intumescence, to a grey glass Decomposed by h acid, with separation of silica. Colmonell (Ayrshire), Porto Ferraio

536 PYCNOTROP

Large grained aggregates Cl along two rectangular faces, fracture hackly, splintery Greyish white to brown red. Vitreous to greasy H = 2 to 2 3, G = 2 6 to 2 7 C c alumina 29 3 magnesia 12 6, potash 4 4, silica 45, water 7 8 Waldheim in Saxony

537 THURINGITE ($\frac{1}{2}\dot{R}$ $\dot{\bar{H}}_3+\frac{1}{2}(\bar{A}l$ $\bar{F}e))_4Si_3+4\dot{\bar{H}}$

Massive scaly H = 2 to 2 5, G = 3 2 Pearly Olive green to pistachio green streak paler Very tough Powder greasy C c alumina 16, peroxide of iron 14 protoxide of iron 33, silica 23, water 11 Schmiedefeld in Thuringia, Harper's Ferry on the Potomac, Hot Springs in Arkansas

538 DELESSITE, $(Fe\frac{1}{4}, Mg\frac{3}{4})_2Si_2+(\bar{A}l\frac{1}{10}, \bar{F}e\frac{9}{10})Si+3\bar{H}+2Mg\dot{\bar{H}}$

Massive scaly H = 2 to 2 5 G = 2 6 to 2 89 Olive green to dark green, passing to dark brick red, streak light green C c alumina 16 3, protoxide of iron 12 6 magnesia 21, silica 31 5, water 15 8 Common in igneous rocks of Old Red Sandstone and Coal measure age in Scotland Oberstein, Zwickau, Lagrève near Mielin

539 CRONSTEDTITE, $\bar{F}eSi+(Fe, Mg)_3Si+3\bar{H}$

Rhombohedral, radiated columnar In tapering hexagons and hemihedral (figs 495 496) Cl basal perfect elastic H = 2 5 G = 3 3 to 3 5 Vitreous Coal black and brownish black, streak dark olive green C c protoxide of iron 39 peroxide of iron 29 silica 22, water 11 Huel Maudlin in Cornwall, Przibram Brazil (*Sideroschisolite*)

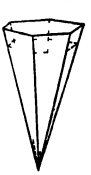


Fig 495 (Sp 539)

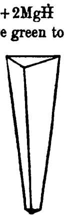


Fig 496

TALC AND SERPENTINE GROUP

540 TALC $Mg_6Si_4+\bar{H}$

Right prismatic (?), rarely found in six sided or rhombic tables, generally massive granular or scaly Rarely fibrous Cl basal, perfect, soft sectile and flexible in thin plates H = 1, G = 2 6 to 2 8 Transparent in thin plates and optically binaxal, pearly or resinous. Colourless, but generally greenish or yellowish white to apple or olive green Feels very greasy B B emits a bright light, exfoliates, and hardens (H = 6), but is infusible, with cobalt solution becomes red Not sol in h or s acid before or after ignition C c 63 5 silica, 31 7 magnesia, and 4 8 water Unst in Shetland green, Cairnie in Aberdeenshire, brown, Greiner in Tyrol, Sala and Falun, the Pyrenees Used as crayons, also for forming crucibles and for porcelain

Steatite — Massive Grey, red, yellow, or green Shetland, Sutherland, Portsoy, and near Kirkcaldy, Scotland; the Lizard Point, Cornwall, Briançon, Wunsiedel Savage nations cut the steatite into culinary utensils

Potstone is a mixture of talc, chlorite, and other minerals.

541 PICROPHYLL, $3\dot{R}Si+2\bar{H}$

Right prismatic H = 2 5, G = 3 75 Dark green Foliated, shining C c magnesia 30 1, protoxide of iron 6 9, silica 49 8, water 9 8 Sala in Sweden

542 PICROSMINE, $2MgSi+\dot{\bar{H}}$

Right prismatic, but massive Cl ∞P̆∞ perfect, less so in other directions, sectile H = 2 5 to 3, G = 2 5 to 2 7 Translucent or opaque, vitreous, but pearly on ∞P̆∞ Greenish white, grey, or blackish green, streak colourless Yields a bitter odour when breathed on, hence the name C c 55 8 silica, 36 1 magnesia, and 8 1 water Presnitz in Bohemia, and Greiner in Tyrol

543 MONRADITE, $4(\frac{5}{6}Mg, \frac{1}{6}Fe)Si+\dot{\bar{H}}$

Massive, foliated, translucent, and yellowish grey H = 6, G = 3 27 C c silica 55 2, magnesia 31 9, protoxide of iron 8 8, water 4 1 B B infusible Bergen in Norway

544 MEERSCHAUM, $2Mg\,Si_3+4\dot{\bar{H}}$

Fracture earthy, sectile H = 2 to 2 5, G = 0 8 to 1 (when moist nearly 2) Opaque, dull Yellowish and greyish white, streak slightly shining Feels rather greasy, and adheres strongly to the tongue C c 54 2 silica, 24 7 magnesia, and from 9 to 21 7 water Negropont, Anatolia, near Madrid and Toledo, Moravia, Wermland.

545 APHRODITE, $4MgSi+\bar{H}$

Soft and earthy G = 2 21 Milk white, opaque C c 52·9 silica, 35 3 magnesia, 11 9 water Långban (Sweden), Elba

546 SPADAITE, $Mg_5Si_6+4\bar{H}$

Massive fracture splintery, sectile H = 2 5 Translucent, resinous Red with white streak C c 57 silica, 31 6 magnesia, 11 4 water Capo di Bove near Rome

547 GYMNITE

Massive H = 2 to 3, G = 1 9 to 2 2 Translucent, resinous. Dull orange yellow C c 41 silica, 37 magnesia, 22 water Tyrol, Passau, Texas, Barehills near Baltimore *Nickel Gymnite* has 29 of nickel oxide, replacing the water Unst, Texas, Pennsylvania

548 SAPONITE, $(\dot{F}e\dot{C}aMg)_6Si_6+(\bar{A}l_3\bar{F}e)Si+13\dot{\bar{H}}$

Massive, sectile, and very soft H = 1 5, G = 2 2 to 2 3 White, orange yellow, pale green, and reddish brown Feels greasy, does not adhere to the tongue, falls to pieces in water C c silica 40 8, alumina 7 5, ferric oxide 3 9, magnesia 20 6, water 22 7 Occurs in all the above colours in the later igneous rocks of Scotland, commonly Lizard Point and St Clear in Cornwall, and Dalecarlia in Sweden *Pimelite* has 2 8 oxide of nickel

549 SERPENTINE, $2MgSi+Mg\dot{\bar{H}}_2$

Crystallization uncertain, pseudomorphic after olivine, &c, generally massive, and granular or fibrous, fracture flat conchoidal, uneven, or splintery, sectile, and slightly brittle H = 3 to 3 5, G = 2 5 to 2 7 Translucent to opaque, dull resinous Green, grey, yellow, red, or brown, often in spots, stripes or veins, streak white, shining Feels greasy, and does not adhere to the tongue In the closed tube yields water, and becomes black C c 43 5 silica, 43 5 magnesia, and 13 water, but with 1 to 8 iron protoxide, and also carbonic acid, bitumen, and chrome oxide

Varieties are—(1) *Noble Serpentine*, brighter coloured, $16H_2O$, and more translucent, (2) *Picrolite*, or fibrous (H = 3 5 to 4 5), (3) *Common*, or compact, (4) *Chrysotile* (*Baltimorite*, *Metaxite*), in fine asbestiform fibres, easily separated, with a metallic or silky lustre (G = 2 219)

Common in Shetland, Urquhart, Portsoy, Ballantrae, Lizard Point in Cornwall, Norway, Sweden, North America Chrysotile at Colafirth and Fetlar, Shetland, Portsoy, Towanreiff, in Scotland, Reichenstein in Silesia, the Vosges Mountains, and North America Serpentine is often a product of decomposition, or pseudomorph of various minerals, as augite, hornblende, olivine, spinel, enstatite, garnet, &c It forms whole rocks and mountains, and is manufactured into various ornamental articles

550 MARMOLITE, $3MgSi+2Mg\dot{\bar{H}}_2$

Oblique prismatic, often foliated H = 2 5 to 3, G = 2 41 to 2 47 Lustre pearly Greenish white, bluish white, and asparagus-green C c silica 42 1, magnesia 38 5, water 17 5 In veins in serpentine of Urquhart and Portsoy (Scotland) Cornwall, Finland, Hoboken

551 ANTIGORITE

Thin flat laminæ H = 2 5, G = 2 6 Translucent Green with brown spots, streak white C c silica 40 8, magnesia 36 3, protoxide of iron 5 8, water 12 4. Antigorio in Piedmont

552 **Hydrophite**, $(Mg, \dot{F}e)_4Si_3 + 4\dot{H}$.

Massive and fibrous H = 3 to 4, G = 2 65 Mountain green to blue black, streak paler C c silica 36 2, magnesia 21 1, protoxide of iron 22 7, water 16 Taberg in Sweden, New York

553 **Villarsite**, $2\dot{M}g_2Si + \dot{H}$

Right prismatic, crystals P, 0P, meeting at 136° 32′, often twins in triple combination, also granular H = 3, G = 2 9 to 3 Translucent Greenish to greyish yellow C c silica 39 6, magnesia 47 4, protoxide of iron 3 6, water 5 8 Totaig, Ross shire, Traversella, Piedmont, Forez, France

554 **Pyrallolite**

Oblique prismatic, C 72° 56′, columnar and granular Cl basic and hemidomatic, meeting at 94° 36, fracture splintery, brittle H = 3 5 to 4, G = 2 6 Translucent on edges, resinous Greenish to yellow grey C c silicate of magnesia and water Storgard in Finland

555 **Dermatine**, $(Mg, \dot{F}e)Si + 2\dot{H}$

Reniform, stalactitic, fracture conchoidal, brittle H = 2 5, G = 2 1 Resinous Blackish green, streak yellow Does not adhere to tongue C c silica 38, magnesia 22, protoxide of iron 12, water 23 Waldheim in Saxony

556 **Chlorophæite**, $\dot{R}Si + \bar{R}_2Si_3 + 4\dot{H}$

Massive, rarely reniform Coating or filling up geodes in amygdaloidal cavities H = 1 5, G = 2 02 to 2 3 Sectile, fracture conchoidal On first exposure transparent and olive green to orange yellow, but soon changes to black and opaque, splitting in so doing Vitreous to shining. B B melts to a black glass C c silica 36 2, alumina 8 9, peroxide of iron 13 8, protoxide of iron 2 4, lime 3 8, magnesia 10, water 24 8 Rum and Canna in the Hebrides, Giant s Causeway The original mineral from Rum has 22 8 iron peroxide and no alumina

557 **Forchhammerite**, $FeSi + 6\dot{H}$

Granular massive Subresinous to dull Dark green H = 2 G = 1 8 C c silica 32 8, protoxide of iron 21 6, magnesia 3 4, water 42 2 Faroes

558 **Kirwanite**

Fills druses in amygdaloids with divergent sheaf like crystals H = 2, G = 2 9 Opaque Olive green to dark green C c silica 40 5, alumina 11 1, protoxide of iron 23 9, lime 19 8, water 4 4 Loch Baa in Mull, Mourne Mountains in Ireland

559 **Glauconite**

Round grains Dull resinous Light green C c silicate of protoxide of iron and potash Ashgrove near Elgin, greensand of England, France, Germany, and America

560 **Celadonite**, $3\dot{R}Si_2 + \bar{R}_2Si_2 + 5\dot{H}$

Massive, forming crusts, as of agates Earthy, sectile H = 1 to 2, G = 2 6 to 2 8 Opaque, shining Bright green Feels greasy C c silica 54, alumina 3 8, ferric oxide 11 9, ferrous oxide 5 4, magnesia 6 8, potash 7 9, water 10 Orkney, Rum, and Fifeshire in Scotland Giant s Causeway, Verona, Faroes, Iceland, Cyprus, Bohemia

561 **Stilpnomelane**, $2(\dot{F}e, Mg)Si + \bar{A}lSi + 2\dot{H}$

Massive or radiating foliated One cl perfect, brittle H = 3 to 4, G = 3 to 3 4 Opaque, vitreous to pearly Greenish black C c 45 3 silica, 6 9 alumina, 38 3 iron protoxide (with 2 to 3 magnesia), and 9 5 water Zuckmantel in Silesia and Weilburg in Nassau

562 **Chamoisite**

Oolitic and massive H = 3, G = 3 to 3 4 Greenish grey to black, streak paler C c silica 14 3, alumina 7 8, protoxide of iron 60 5, water 17 4 Chamoison (or Chamoson) in Valais, the Vosges *Berthierine* has 75 protoxide of iron and 5 of water, Moselle

Augite and Hornblende Group [1]

Hornblende and augite rather represent groups of mineral substances than single species They are best distinguished when imperfectly formed, by the cleavage and angles of the prisms

563 **Enstatite** (*Chladnite*), $MgSi$.

Right prismatic ∞P 92° to 93°; crystals $\infty\bar{P}\infty$ (*a*), $\infty\breve{P}\infty$ (*b*), ∞P (*m*), $\frac{1}{2}\breve{P}\infty$ (*k*), $\frac{2}{3}\breve{P}\infty$ (*q*), $\breve{P}\infty$ (*ψ*), $\frac{2}{3}P$ (*τ*) (fig 497) Usually imbedded, or indistinct granular masses Cl macrodiagonal very perfect, prismatic ∞P distinct, brachydiagonal imperfect H = 5 5, G = 3 1 to 3 3 Translucent throughout, or only on the edges, vitreous or pearly on the more perfect cleavage planes Colourless, greyish or greenish white, yellowish, or brown Not affected by almost infusible C c 60 silica and 40 magnesia, but with 6 to 8 iron protoxide, 1 to 2 alumina, and 1 or 2 water In olivine and serpentine rocks in Moravia, the Harz (Baste), and the Pyrenees

Fig 497

564 **Bronzite** (*Schiller Spar, Bastite*), $(Mg, Fe)\dot{S}i$

Right prismatic ∞P 94°, only granular and foliated. Cl brachydiagonal perfect, prismatic less so, fracture uneven, splintery H = 4 to 5, G = 3 to 3 5 Translucent on thin edges, metallic pearly Green, inclining to yellow or brown Imperfectly sol in h acid, wholly in s acid B B becomes magnetic, and fuses in very thin splinters C c 43 silica, 26 magnesia, 2 7 lime, 7 4 iron protoxide, 3 3 iron peroxide, 2 4 chrome oxide, 1 7 alumina, and 12 4 water *Bastite* is possibly altered enstatite Belhelvie and Black Dog in Aberdeenshire, Baste, Tyrol, Baireuth, Styria

565 **Paulite** (*Hypersthene*), $(Fe\ Mg)Si$

Right prismatic ∞P (*m*) 93° 30, $\bar{P}2$ (*c*), $2\bar{P}2$ (*i*), $\frac{3}{2}\bar{P}\frac{3}{2}$ (*u*), $\infty\breve{P}2$ (*n*), $\frac{1}{4}\breve{P}\infty$ (*h*), $\infty\bar{P}\infty$ (*a*) $\infty\breve{P}\infty$ (*b*) $\frac{1}{2}\breve{P}\infty$ (*k*) $2\bar{P}\infty$ (*d*) Granular or disseminated Cl brachydiagonal very perfect, prismatic ∞P distinct, macrodiagonal very imperfect H = 6, G = 3 3 to 3 4 Opaque or translucent on thin edges, vitreous or resinous, but metallic pearly on the cleavage planes, of which one is copper coloured to violet or silvery Pitch black and greyish black, streak greenish grey or pinchbeck brown inclining to copper red Not affected by acids B B melts more or less easily to a greenish black glass, often magnetic C c generally 46 to 58 silica, 0 to 4 alumina, 11 to 26 magnesia, 1 to 5 lime, 13 to 34 iron protoxide, 0 to 6 manganese protoxide Portsoy and Craig Buroch in Banffshire Barra Hill in Aberdeenshire, Paul s Island, Labrador, and Greenland Crystals occur in sanadine bombs at Lake Laach (*Amblystegite*), and in meteorites of Breitenbach Hypersthene rock in Norway, Elfdal in Sweden, Cornwall (?) the Harz, and Canada. Chemically enstatite and paulite pass into one another, the essential difference is that the axial dispersion is uniformly $\rho < \nu$ in the former, and the opposite in the latter

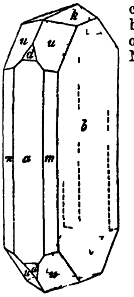


Fig 498

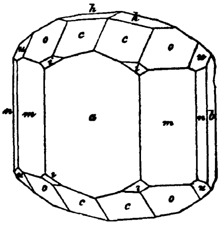


Fig 499

566 **Wollastonite** (*Tabular Spar*), $\dot{C}aSi$

Oblique prismatic, C 84° 30 ∞P 87° 18′, 0P (*u* or *h′*), $\infty\bar{P}\infty$ (c or *p*), $\infty P\frac{3}{2}$ (*z*) 110° 7′, $\infty P^{c}2$ (*x* or *e*) 51°, $-\bar{P}\infty$ (*v*) 44° 27, $\frac{1}{2}\bar{P}\infty$ (*a*) 69° 56′ (fig 500) Rarely crystallized, mostly broad prismatic or laminar Frequently fibrous Cl along 0P and $\infty P^{o}\infty$ perfect, but planes uneven or rough, meet at 95° 23′ H = 4 5 to 5, G = 2 8 to 2 9 Translucent, vitreous or pearly on cleavage White inclining to grey, yellow, red, or brown, streak white

Fig 500

---

[1] Hornblende and augite agree so closely in crystalline forms and chemical composition that it has sometimes been proposed to unite them in one species. They, however, differ too widely to justify their union Hornblende is more fusible and ranges lower in specific gravity (hornblende from 2 931 to 3 445, augite 3 195 to 3 525) Though both possess a cleavage parallel to their vertical prisms, yet these differ in angular dimensions —hornblende 124° 12′, augite 87° 6 They also occur in distinct geognostic positions —hornblende in rocks containing quartz or free silica, and mostly with minerals that are neutral compounds of silica, as orthoclase and albite, augite in rocks that do not contain free silica, and mostly with minerals that are not neutral silicates, as labradorite, olivine and leucite Hence there are two distinct series of massive or igneous rocks —the hornblende series including granite, syenite diorite, diorite porphyry and red porphyry, and the augite series or hypersthene rock, gabbro dolerite, nepheline rock, augite-porphyry, and leucite porphyry

Phosphoresces with heat or friction gelatinizes in h acid B B difficultly fusible to a semitransparent glass C c 51 7 silica and 48 3 lime, but with 0 to 2 magnesia and 0 to 2 iron protoxide Glen Gairn Crathie &c, in Aberdeenshire, Urquhart in Inverness, Skye Banat, Finland, Sweden Vesuvius (fig 501), North America, Ceylon, Capo di Bove

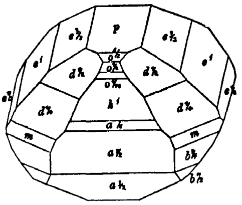


Fig 501 (sp 566)

567 AUGITE (*Pyroxene*), $RSi=(Ca, Mg, Fe)Si$

Oblique prismatic, C 74° 11 ∞P 87° 6 , P (s s) 120° 48 , − P (u) 131° 30 , 2P (o) 95° 48 , 0P, 3P, $\infty P^{\circ}\infty$ In fig 130 ∞P (*M*), $\infty P^{\circ}\infty$ (*r*), $\infty P^{c}\infty$ (*l*), P(*s*), also various twins and hemitropes of same form (figs 191, 502, 503) Almost always prismatic, imbedded, or attached, granular, columnar, and scaly Cl prismatic along ∞P (with angles of 87° 6′ and 92° 54), generally rather imperfect, orthodiagonal and clinodiagonal imperfect H = 5 to 6, G = 3 to 3 5 Pellucid in all degrees, vitreous, in some pearly on $\infty P^{\circ}\infty$ Colourless, and white, but usually grey, green, or black B B generally fusible, imperfectly soluble in acids C c generally as follows —

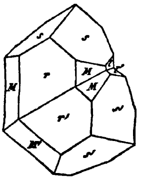


Fig 502

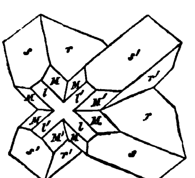


Fig 503

	Silica	Lime	Magnesia	Iron
(*a*) Magnesia augite	56 22	25 54	18 24	
(*b*) Magnesia iron augite	[illegible]	23 81	8 50	14 97
(*c*) Iron augite	49 06	22 29		28 65

Analysis gives 47 to 56 silica, 20 to 25 lime, 5 to 15 magnesia, 1 to 20 iron protoxide, with 0 to 3 manganese protoxide and 0 to 8 alumina. The alumina, chiefly found in very dark green or black augites, may in some replace either silica or part of the silicate

The more important varieties are—

Diopside —Greyish or greenish white, to pearl grey or leek green, streak white Crystallized or broad columnar, or concentric lamellar Transparent to translucent on the edges Not affected by acids B B fuses to a whitish semitransparent glass C c generally lime 26 and magnesia 18 5, with 55 5 silica Mussa Alp (***Mussite***) and Ala (*Alalite*) in Piedmont, Schwarzenstein in Tyrol, Scandinavia, Finland, Urals and North America

Malacolite, Sahlite —White, green, rarely yellow, brown, or red, streak white Translucent or only on the edges, vitreous, inclining to pearly Seldom crystallized, mostly columnar or lamellar B B melts to a dark-coloured glass. Malacolite common in primary limestones in Scotland, as at Shinness, Ledbeg (fig 505), and Glen Tilt Fassa Valley (*Fassaite*), Piedmont Arendal, Philipstadt in Sweden, Lake Baikal (*Baikalite*) near Lake Lherz in the Pyrenees (*Lherzolite*), Sala (or Sahla) in Sweden (*Sahlite*), Shinness (figs 504, 506), Glenelg, Tiree, in Scotland, Tyrol, North America *Coccolite* is a granular sahlite or augite

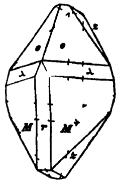


Fig 505.

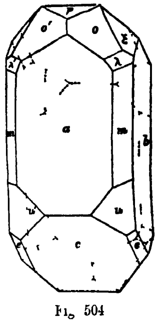


Fig 504

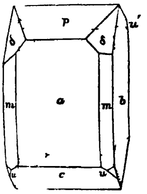


Fig 506

Augite —Leek green greenish black, or velvet black, rarely brown, streak greenish grey Vitreous to resinous, translucent or opaque Only slightly affected by acids B B fuses to a black, often magnetic glass An essential component of many rocks, as basalt, dolerite, clinkstone, and augite porphyry, Germany, Auvergne, Vesuvius, St Kilda, Rum, Tiree, Dalnain, and Urquhart in Scotland Augite crystals in basalt often contain very many microscopic crystals and glasses, also pores with fluid carbonic acid.

Hudsonite —Cleavable lamellar, and jet black, with green streak and bronzy tarnish, from the Hudson river, the most highly ferruginous variety

Amianthus—Some asbestiform minerals are augite, but the greater number hornblende

Breislackite —Fine yellowish or brown woolly crystals Vesuvius, and Capo di Bove near Rome

568 DIALLAGE, $(\dot{C}a, Mg, \dot{F}e) Si$

Like augite, and only a variety with very perfect cleavage in the clinodiagonal, which forms with a second cleavage an angle of 87° Lustre metallic pearly, colour grey or pinchbeck brown H = 4, G = 3 23 B B melts easily to a greyish or greenish enamel C c 50 to 53 silica, 1 to 5 alumina, 15 to 23 magnesia, 11 to 20 lime, and 5 to 20 manganese protoxide Constituent of the augite rock of the Cuchullins in Skye and of the gabbro of Unst and Ayrshire Baste in the Harz, Silesia, the Alps, Apennines, and Urals *Vanadine Bronzite*, containing soda and vanadic acid, is similar At Craig Buroch (Banffshire) diallage passes in paulite

569 JEFFERSONITE

Oblique prismatic Cl prismatic ∞P 87° 30′, and orthodiagonal H = 4 5, G = 3 3 to 3 5 Dark olive green, brown to black Lustre greasy A manganese and zinc augite, with 10 2 protoxide of manganese, and 10 15 oxide of zinc Sparta in New Jersey

570 ACMITE, $2\bar{F}eSi_3+3RSi$

Oblique prismatic Crystals long often acute pointed prisms ∞P 87° 15, $\infty\bar{P}\infty$ (*r*), P(*s*), 6P (*o*), $-6P^{c}3$(*z*) (figs 507, 508) Cl like augite H = 6 to 6 5, G = 3 4 to 3 6 Nearly opaque, vitreous Brownish or greenish black, streak greenish grey Imperfectly soluble in acids B B fuses easily to a black magnetic glass C c 52 silica, 30 iron peroxide, 5 iron protoxide, and 13 soda, but with 1 to 3 manganese peroxide, and also 3 to 4 titanic acid Eger and Porsgrund in Norway

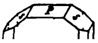


Fig 507 (Sp 570)

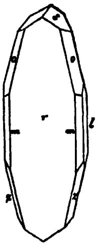


Fig 508

571 ÆGERINE, $R_2Si_5+\bar{R}Si+2NaSi$

Oblique prismatic, striated or reed like prisms of 86° 30′ to 87° 45′ Cl orthodiagonal perfect, less distinct clinodiagonal, and prismatic H = 5 5 to 6, G = 3 4 to 3 5 or 3 6 Vitreous, translucent on edges, or opaque Greenish black B B fuses easily, colouring the flame yellow Scarcely affected by acids C c 49 silica, 31 7 iron peroxide, 6 6 iron (and manganese) protoxide, and 12 7 soda, with a little magnesia and potash Has the same relation to augite as arfvedsonite to hornblende Near Brevig and Barkevig in Norway.

572 SPODUMENE, $4\bar{A}lSi_3+3(\dot{L}i, \dot{N}a, \dot{K})Si$

Oblique prismatic, C 69° 40 ∞P 87° (fig 509) Cl prismatic ∞P and orthodiagonal, perfect, chiefly massive or foliated H = 6 5 to 7, G = 3 1 to 3 2 Translucent, vitreous or pearly Pale greenish grey or white to apple green, streak white B B intumesces slightly, tinging the flame momentarily purplish red, and fuses easily to a colourless glass Not affected by acids C c 65 silica, 28 7 alumina, and 6 3 lithia Killiney near Dublin, Uto in Sweden, Tyrol *Killinite* (sp 651), from Killiney, seems to be decomposed spodumene

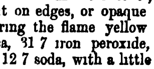


Fig 509 (sp 572)

573 PETALITE (*Castor*), $4\bar{A}lSi_6+3(\dot{L}i, \dot{N}a)Si$

Oblique prismatic Castor has C 67° 34 and ∞P 86° 20, in irregular rectangular prisms, petalite being massive and coarse granular Cl basal, distinct, in a second direction (meeting at 141½°) less so H = 6 5, G = 2 4 to 2 5 Greenish, greyish, or reddish white to pale red Translucent, vitreous or pearly B B melts easily into a porous obscure glass, colouring the flame red Not affected by acids C c 78 3 silica, 17 4 alumina, 3 2 lithia, and 1 1 soda Uto, Bolton in Massachusetts, York in Canada *Castor* in Elba *Milarite*, valley of Milar, Switzerland

574 **Rhodonite** (*Manganese Spar*), MnSi

Anorthic $\infty\breve{P}\infty$ (*a*), $\infty\bar{P}\infty$ (*b*) 0P (*c*) ∞P (*u*) $\breve{P}\infty$ (*k*), $\bar{P}\infty$ (*s*), $'\bar{P}\infty$ (*o*), *m* $\bar{P}\infty$ (*t*) *a* *b* 111° 9′, *c* *a* 93° 28, *n* *a* 106° 19, but chiefly massive or granular Cl $\infty P\infty$ and 0P, meeting at 87° 38, perfect, brittle H = 5 to 5 5, G = 3 5 to 3 7 Translucent, vitreous or partly pearly Dark rose red, bluish red or reddish brown Not affected by acids B B fusible C c 45 8 silica and 54 2 manganese protoxide with 3 to 5 lime and 0 to 6 iron protoxide St Marcel, Långban, Ekaterinburg the Harz, and New Jersey *Bustamite*, pale greenish or reddish grey, with 14 lime, Mexico, *Fowlerite*, New Jersey, with 7 to 11 iron protoxide and *Paisbergite*, Sweden, are varieties *Hydropite*, *Photicite*, *Allagite* and *Horn Manganese* are mere mixtures

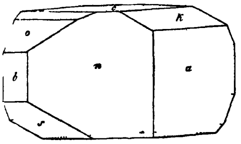


Fig 510

575 **Babingtonite**, 9(Ca, Fe, Mn)Si + $FeSi_3$

Anorthic Crystals very low eight sided prisms, small, attached *g* *h* 90° 24, *c* *a* 87° 27 *a* *b* 112° 12, *b* *d* 81° 8, *c* *d* 150° 10 (fig 511) Cl basal (*c*), very perfect also along *b* H = 5 5 to 6, G = 3 3 to 3 4 Thin laminæ translucent Splendent vitreous, black Not affected by acids B B fuses easily with effervescence to a black magnetic bead C c 50 7 silica, 11 iron peroxide, 10 3 iron protoxide, 7 7 manganese protoxide, and 20 3 lime, in the Arendal specimens, one from Nassau gave about 17 of peroxide with protoxides only 11 Tongue (Sutherland), Portsoy (Banffshire), Arendal, Nassau, and Gouverneur (New York)

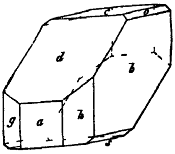


Fig 511

576 **Szaboite**, $11FeSi_3 + 2CaSi$

Anorthic ∞P (*l*) ∞ P (*m*) 88° 40, $\infty\breve{P}\infty$ (*b*) $\infty\bar{P}\infty$ (*a*), P (*p*), P (*o*), $2\breve{P}\infty$ (*y*), $2\breve{P}\infty$ (*x*) (fig 512) H = 6 5, G = 3 5 Brownish red to reddish yellow Pleochroic C c silica 52 4, peroxide of iron 44 7, lime 3 1 Slightly sol in s acid, more so in h acid Calvario on Etna, Mont Dore

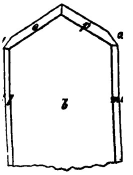


Fig 512 (sp 576)

577 **Anthophyllite**, 3MgSi + FeSi

Right prismatic ∞P 124° 30 Cl macrodiagonal, perfect Clove brown to purplish brown and leek green Translucent, radiating and foliated Pearly on cl plane H = 5 5 G = 3 2 C c silica 55 9, protoxide of iron 16 7, magnesia 27 8 B B very difficultly fusible Hillswick, Shetland Kongsberg and Modum, Norway, Greenland, and the United States

578 **Hornblende**

Oblique prismatic (figs 513 to 517, see also fig 192) Distinct cleavage in several directions H = 4 to 6, but generally 5 (will scratch with knife), G = 2 5 to 4 0, but mostly high Mostly coloured Lustre vitreous, in some silky or metallic pearly Sol, but not very readily, in acids, more or less easily fusible C c anhydrous silicates and aluminates of lime, magnesia, iron protoxide, more sparingly of soda, yttria, and manganese protoxide The chief species form by their decomposition highly fertile soils

Amphibole—Oblique prismatic, C 75° 10 ∞P 124° 30, P 148° 30 The crystals short and thick, or long and thin prismatic, formed especially by ∞P (*m*), $\infty P\infty$ (*x*), and bounded on the ends chiefly by 0P (*p*) and P (*r*) Twins common, with the chief axis the twin axis Very often radiated, fibrous, or columnar, or granular Cl prismatic along ∞P 124½°, very perfect, orthodiagonal and clinodiagonal very imperfect H = 5 to 6, G = 2 9 to 3 4 Pellucid in all degrees, vitreous, but sometimes pearly or silky Colourless or white, but usually some shade of grey, yellow, green, brown, or black B B fuses, generally intumescing and boiling, to a grey, green, or black glass Those containing most iron are most fusible, and are also partially sol. in h. acid, which scarcely affects the others C c very variable, the silica is partly replaced by alumina, specially in the green or black varieties, RO is chiefly MgO, CaO, and FeO Lime is the most constant element, in most from 10 to 12 magnesia and iron protoxide replace each other, the one increasing as the other diminishes

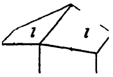


Fig 514

With 4Si and R = 2Mg + 1Ca + 1Fe, the average composition is 53 6 silica 17 8 magnesia, 12 5 lime, and 16 1 iron protoxide, but analyses give 40 to 60 silica, 0 to 17 alumina, 0 to 30 magnesia, 10 to 15 lime, 0 to 36 iron protoxide (or peroxide), and 0 to 4 manganese protoxide, 0 to 8 soda, 0 to 3 potash, and 0 to 1 5 fluorine with a little water

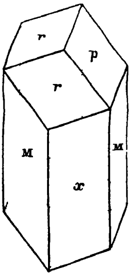


Fig 515

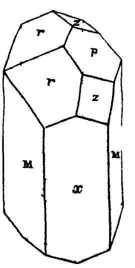


Fig 516

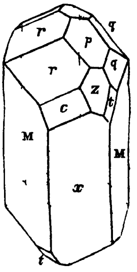


Fig 517

The more important varieties are—

Amianthus, *Asbestos*, and *Byssolite*, 2MgSi + CaSi Fine fibrous White, grey, or green The fibres often easily separable, elastic, and flexible Unst, Shinness, Portsoy, Savoy, Tyrol, Corsica

Tremolite, *Grammatite*, 3MgSi + CaSi, with 58 35 silica, 28 39 magnesia, and 13 26 lime White, grey, green, in long prismatic crystals, often striated longitudinally Pearly or silky, semitransparent or translucent B B fuses readily to a white or nearly colourless glass Loch Shin (Sutherland), Glen Tilt, Glenelg, Tiree, Cornwall, Cumberland, Sweden, the Alps, Pyrenees, Silesia, Siberia, North America

Nephrite, or *Jade*, is a tough, compact, fine grained tremolite, with H = 6 to 6 5, G = 2 9 to 3 1 Fracture close splintery Very tenacious Translucent dull to resinous Leek green to blackish green Feels slightly greasy Formerly made into ring stones, amulets, idols, and war axes New Zealand, China, Mexico, Peru, Balta (Shetland)

Actinolite, *Actinote*, or *Strahlstein* (Ca, Mg, Fe) Si Colour green, inclining to black, grey, or brown Translucent throughout, or only on the edges Long prismatic crystals, or radiated columnar masses B B melts to a greenish or blackish enamel Fethaland and Colafirth and Hillswick (Shetland), Oronsay, Ord Ban (Inverness), Sweden, Tyrol, North America

Hornblende—$6RSi + R_2Si_3$ Green or black, seldomer brown or grey G = 3 1 to 3 3 B B fuses rather easily to a yellow, greenish, or black enamel Three varieties are distinguished (*a*) The noble or *Pargasite*, pale celadon or olive green, and strong pearly or vitreous lustre, at Pargas in Finland, Tyrie in Scotland (*b*) Common hornblende, dark leek or blackish green, opaque, streak greenish grey A constituent of many rocks, as in Norway, the Alps, and Scottish Highlands (Ballater Ben Anhaar, Glenbucket, Colafirth) (*c*) Basaltic, foliated, with bright even cleavage opaque, velvet black, streak grey or brown Generally contains alumina (9 to 15) and much (5 to 11) iron peroxide In basalt and volcanic rocks. Etna, Vesuvius, Rhineland, Bohemia.

579 ARFVEDSONITE, $RSi+FeSi_3$

Oblique prismatic ∞P, ∞P̄∞, P, 2P̄∞ 120° 24, 0P Cl ∞P 124° 22, perfect also 0P Massive Black, opaque Vitreous H = 6 G = 3 44 C c silica 43, alumina 4 5, peroxide of iron 3 8, protoxide 34, lime 5 7, soda 8 5 Streak dark blue grey Fusible in fine splinters in the flame of a candle B B intumesces and melts easily to a black magnetic globule Not sol in acids Kangerdluarsuk in Greenland, Frederiksvarn, Arendal, El Paso in Colorado

580 PILOLITE, $4MgSi_2+AlSi_2+15H$

Felted or matted fibres more or less dense Cream yellow to buff Dull, extremely tough absorbs water like a sponge H = 1 to 2 5, G = 68 to 1 34 Structure varies considerably, and has given rise to trivial names, as mountain paper, mountain leather mountain flesh, rock cork, &c *Mountain Paper* occurs in thin sheets at Boyne Castle near Banff, *Mountain Leather*, Burn of the Cairn (Cabrach), Tod Head (Kincardineshire), Leadhills, Strontian, *Rock Cork* Portsoy and Boyne Castle, Saxony, and Sweden C c silica 51 6, alumina 8 6, ferrous oxide 2 88, magnesia 10 2, water 23 3

581 KROKIDOLITE, $3FeSi+(Na,Mg)Si+2H$

Delicate easily separable, but tough fibres, elastic H = 4, G = 3 2 to 3 3 Translucent, silky Indigo blue, streak lavender B B fuses easily to a black magnetic glass C c silica 50 3, iron protoxide 35, magnesia 2 2, soda 6 7, water 5 8 Stavern in Norway Greenland A fibrous yellow mineral from Orange river, South Africa, has been referred here, its fibres are not separable, and its hardness is 7 *Abriachanite*, a very similar mineral, of blue colour, occurs near Inverness

582 GLAUCOPHANE, $9RSi+2AlSi_3$

Oblique prismatic Cl prismatic, perfect, fracture conchoidal H = 5 5, G = 3 1 Translucent, vitreous to pearly Indigo blue grey, bluish black B B becomes brown, fusing easily to olive green glass C c silica 56 5, alumina 12 2, protoxide of iron 10 9, magnesia 8, soda 9 3 Island of Syra

583 HERMANNITE, $MnSi$

Granular and arborescent Rose red G = 3 4 C c protoxide of manganese 46 7, silica 48 9, lime 2, magnesia 2 4 Cummington in Massachusetts

584 GRUNERITE, $FeSi$

Asbestiform G = 3 7 Brown silky lustre C c protoxide of iron 51 55, silica 45 45 Mt des Maures (Var)

585 IOLITE (*Cordierite, Dichroite*), $AlSi_3+2(Mg,Fe)Si$

Right prismatic ∞P (*P*) 119° 10, middle edge of P 95° 36 Form ∞P (*T*), ∞P̆∞ (*l*), 0P (*m*), and this with ∞P̄∞ (*k*) ∞P̆3 (*d*), P̆∞ (*n*), and ½P (*s*), (fig 518) short, prismatic Cl ∞P̄∞ distinct, traces along P̄∞, fracture conchoidal or uneven H = 7 to 7 5 G = 2 5 to 2 7 Transparent or translucent, vitreous inclining to resinous Colourless but chiefly dark blue, or violet green brown yellow, and grey Often with distinct trichroism, on 0P blue, on ∞P̄∞ grey and on ∞P̆∞ yellowish B B fuses difficultly to a clear glass, slightly affected by acids C c 48 to 51 silica, 29 to 33 alumina, 8 to 13 magnesia, 1 to 12 iron protoxide Cabo de Gata in Spain, Bodenmais (*Peliom*), Orijerfvi in Finland (*Steinheilite*), Norway, Sweden, Greenland, North America, and Siberia Small rolled masses of an intense blue colour and transparent, found in Ceylon are the *Sapphire d'Eau* or *Luchssapphir* of the jewellers

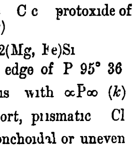


Fig 518

The following have been considered cordierite altered, or with 2 to 6 atoms water —(*a*) *Bonsdorfite, Hydrous Iolite*, greenish brown or dark olive green near Åbo (*b*) *Esmarkite, Chlorophyllite*, large prisms or foliated green or brownish, near Cabrach (Aberdeen), [illegible]

[illegible] Falun (*d*) *Huronite*, granular, pearly, yellowish green H = 3 3, G = 2 86, infusible and insoluble, Lake Huron (*e*) *Weissite*, kidney shaped and ash grey or brown, Falun and Lower Canada (*f*) *Pyrargillite*, indistinct imbedded crystals, black passing into brown or red, dull resinous lustre, H = 3 5, G = 2 5, Helsingfors (*g*) *Pinite*, crystallized, or massive and laminar, with imperfect cleavage, H = 2 to 3, G = 2 7 to 2 9, semitranslucent or opaque, dull or resinous, and dirty grey, green, or brown, B B fuses to a glass, sometimes clear, at other times dark coloured, Auvergne, Schneeberg, Penig in Saxony, the Harz, Cornwall, Cabrach and Torry (Aberdeenshire), [illegible] (*h*) [illegible], opaque, dull resinous, and greenish grey or brown, B B intumesces slightly, and fuses easily to a greenish slag, Tammela in Finland (*i*) *Praseolite*, lamellar and green, Brevig in Norway

586 EMERALD (*Beryl*), $AlSi_3+3\dot{G}lSi$.

Hexagonal, P 59° 53 Crystals of ∞P, 0P, and ∞P, ∞P2, 0P, P (*a*, *p*, *c*, *s*, fig 519) are prismatic, generally with vertical striae Cl basal, rather perfect, ∞P imperfect H = 7 5 to 8, G = 2 6 to 2 8 Transparent or translucent, vitreous Colourless or white, but generally green, sometimes very brilliant, also yellow and smalt blue B B melts with difficulty on the edges to an obscure vesicular glass Not affected by acids C c 67 5 silica, 18 7 alumina, and 13 8 glucina with 0 3 to 3 iron peroxide, and 0 3 to 3 5 chrome oxide in the rich green emerald *Emerald* rich green, G = 2 710 to 2 759, occurs in Muso Valley near Bogota, also in Salzburg and the Urals *Beryl*, or *Aquamarine*, colourless, or less brilliant G = 2 677 to 2 7.. near Mursinsk and Nertchinsk in Siberia, Salzburg, and Brazil in the United States, where at Grafton, between the Connecticut and Merrimack, crystals 4 to 6 feet long and weighing 2000 to 3000 lb, occur, Mourne Mountains in Ireland, Mount Battock and Cairngorm in Scotland (fig 98) *Common Beryl* at Falun in Sweden Fossum in Norway, Limoges in France, Rabenstein in Bavaria, Nigg Bay and Pitfodels and Rubislaw near Aberdeen (*Davidsonite*) Struy Bridge (Ross) Emerald and beryl are much valued as precious stones Known from quartz by face *p* Forms shown in figs 92 95 96, 97, 98, 276

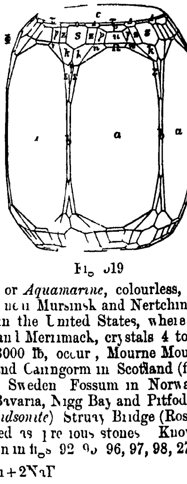


Fig 519

587 LEUCOPHANE, $6CaSi+3GlSi+2NaF$

Right prismatic ∞P 91° Cl basal perfect H = 3 5 to 4, G = 2 97 Pellucid Wine yellow to olive green Vitreous B B fuses to pale violet blue bead C c silica 47, lime 23 4, glucina 10 7, soda 11 3, fluorine 6 6 Lamo in Norway

588 MELINOPHANE, $7(R_3Si_2)+6NaF$

Pyramidal P 122° 23 Mostly lamellar H = 5, G = 3 Honey yellow to citron yellow Brevig and Frederiksvarn

FELSPAR GROUP

Crystallization oblique prismatic or anorthic, very similar both in aspect and in angles Cl very distinct, especially the basal P, less so the clino or brachydiagonal M G = 2 4 to 3 2, but mostly 2 5 to 2 8, H = 6 or a little more Slightly or not at all soluble in acids B B fusible, but often with difficulty Translucent, pure varieties transparent Colourless, white or shades of red, less commonly of green or yellow C c anhydrous silicates of alumina, and of an alkali or alkaline earth

The felspars are very important constituents of the earth's crust, occurring in nearly all the igneous rocks, and in many of the stratified crystalline schists In true strata they are found chiefly as fragments or decomposed, and in the latter state form a large part of wet soils and clays By the older mineralogists and in popular language many species are conjoined under the common name of *felspar* which are now considered as distinct each of them having not only its peculiar physical and chemical characters, but also geognostic position and associated groups of minerals Thus orthoclase, and the other more siliceous felspars with potash, abound in granite and the plutonic rocks, the less siliceous, with soda and lime, characterize the volcanic rocks,—*e g*, labradorite the basaltic group, glassy felspar the trachytic Orthoclase is associated with quartz, hornblende, and mica, glassy felspar either with hornblende and a black mica or with augite, labradorite with augite, very rarely with quartz or hornblende

The felspars are best known from similar minerals by their hardness (they scarce scratch with a good knife), difficult fusibility, and unequal cleavages The following marks may aid the student in distinguishing the more common species In orthoclase the basal cleavage plane forms a right angle with the clinodiagonal cleavage planes *M* on both hands, in the triclinic or plagioclase felspars the angles are unequal Orthoclase, albite, andesine, and oligoclase are insoluble in acids, labradorite and anorthite are more or less soluble In granite, when decomposing, orthoclase often becomes reddish or dark red, oligoclase dull green, and at length white.

Walterhausen considers that the felspars are mixtures of three true species, forming a series with the oxygen of the silica, alumina, and RO in the proportions x 3 1,—x ranging from 24 to 4. Tchermak and most mineralogists now take a similar view, regarding orthoclase, albite, and anorthite alone as true species, of which the others are mixtures Those consisting essentially of potash and soda only are mechanical mixtures of orthoclase and albite, the distinct lamellæ being visible by the microscope, those again that contain essentially lime and soda together [illegible] proportions, and with corresponding transitions in crystallographic and physical properties Notwithstanding this, these intermediates must be regarded as independent mineral species, inasmuch as they are severally typical of certain rocks, and have characteristic forms differing from each other in angular inclination

589 ORTHOCLASE, $\cancel{\mathrm{Al}}\mathrm{Si}_3+\cancel{\mathrm{K}}\mathrm{Si}_3$

Oblique prismatic, C = 63° 57′ ∞P (*T* and *l*) 118° 47 , $\mathrm{P}^{\circ}\infty$ (*x*) 65° 46′, $2\mathrm{P}^{c}\infty$ (*n*) 90° 71 , $2\mathrm{P}^{\circ}\infty$ (*y*) 35° 45 The commonest and simplest forms are ∞P, 0P, $\mathrm{P}^{\circ}\infty$, and $\infty\mathrm{P}^{c}\infty$ (*M*), ∞P, 0P (*P*), $2\mathrm{P}^{\circ}\infty$ (figs 520 to 527) When ∞P predominates the crystals are short rhombic prisms, when $\infty\mathrm{P}^{c}\infty$ predominates they are tabular, when ∞P and $\infty\mathrm{P}^{c}\infty$ predominate they are short hexagonal prismatic, when 0P and $\infty\mathrm{P}^{c}\infty$ they are rectangular prismatic, often much lengthened Twins are very frequent, and occur according primarily to four laws *First*, through revolution of one half or of a whole crystal, then forming interpenetrating twins round a vertical axis (fig 195) In the case of this hemitropic revolution one of the external faces becomes a face of union According as the right or the left half (or whole crystal) is conceived to be that which has been revolved the crystals are termed right and left, as in figs 188, 189 *Second*, by revolution of one half around an axis normal to *M*, in such twins the composition is not evidenced externally except by sutures *Third*, through revolution round an axis normal to *P*, forming orthorhombic prisms which show a herring bone lineation, through the meeting of striæ commonly present upon the face *M* parallel to the intersection of its edge with the face *T* (fig 528) *Fourth*, by revolution round an axis normal to $2\mathrm{P}^{c}\infty$ (*n*), this also forms a prism the section of which is nearly square (fig 529) Compound twins on this last type are formed of 3 to 4 and 8 crystals (fig 530)

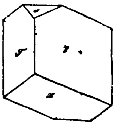


Fig 520

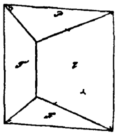


Fig 521

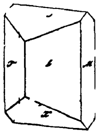


Fig 522

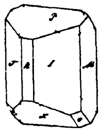


Fig 523

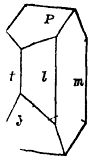


Fig 524

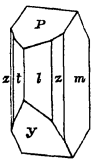


Fig 525

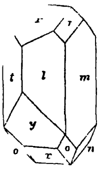


Fig 526

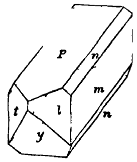


Fig 527

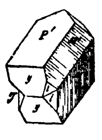


Fig 528

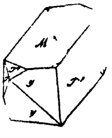


Fig 529

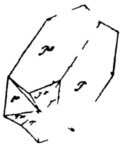


Fig 530

Occurs also massive, and coarse or fine granular Cl basal (*P*), very perfect, clinodiagonal (*M*), perfect (*P* *M* = 90°), fracture conchoidal or splintery H = 6, G = 2 53 to 2 58. Transparent to translucent on the edges, vitreous but pearly on cl, and also opalescent, with bluish or changing colours. Occasionally colourless but generally red, yellow, grey, or green. B B fuses with difficulty to an opaque vesicular glass Not affected by acids C c: 64 6 silica, 18 5 alumina, and 16 9 potash, but generally 10 to 14 potash, 1 to 4 soda, 0 to 1 3 lime, 0 to 2 iron peroxide Varieties are—

(1) *Adularia* and *Ice spar*, transparent or translucent, splendent, and almost colourless Some with bluish opalescence are named *Moonstone*, St Gotthard, Mont Blanc, Dauphine, Arendal, Greenland, and Ceylon

(2) *Common Felspar*, generally white or red, especially flesh red, a common constituent of many rocks Crystals at Baveno on Lago Maggiore, Lomnitz in Silesia, Mourne Mountains and Wicklow in Ireland, Aberdeenshire (at Rubislaw 6 or 8 inches long) in Scotland, and at Carlsbad and Elnbogen in Bohemia *Amazon Stone* verdigris green, from Sutherland, Lake Ilmen and Colorado, and *Murchisonite*, golden or greyish yellow, from Arran and Dawlish, are varieties

(3) The *Glassy Felspar* or *Sanidine* (C 64° 1 ∞P 119° 16) contains 3 to 12 potash and 3 to 10 soda Crystals imbedded, vitreous translucent, and often much cracked Arran Eigg and other parts of Scotland, Drachenfels, Auvergne, and other countries

Orthoclase occurs in granite, gneiss, and porphyry in many countries It is commonly associated with quartz sometimes, as in the *Graphic Granite* of Sutherland, Harris, and Portsoy, in letter like combinations of the latter It is very liable to decomposition when it is converted especially into kaolin used for manufacturing porcelain and stoneware The adularia or moonstone and the green amazon stone are cut as ornamental stones. *Leelite*, from Biddean nam Bian in Argyllshire and Grythyttan in Sweden is a somewhat siliceous horny lustred flesh coloured compact variety *Petunt e* and *Hornstone* are similar but more impure. *Microcline* is a variety with angle distorted by interstitial penetration, by oligoclase (Sutherland), and by albite (Frederiksvarn, &c)

590 ALBITE, $\cancel{\mathrm{Al}}\mathrm{Si}_3+\cancel{\mathrm{N}}\mathrm{aSi}_3$

Anorthic 0P (*P*) $\infty\breve{\mathrm{P}}\infty$ (*M*) 86° 24, ∞P (*l*) ∞ P (*T*) 122° 15, but angles variable Crystals generally like those of orthoclase, are tabular or prismatic (fig 197) Hemitropes common, especially united by a face of $\infty\breve{\mathrm{P}}\infty$ (figs 531, 532) the re entering angle between the faces of 0P (*P* and *P′*) 172° 48 being very characteristic. Fig 198 is another common hemitrope Also massive, and in radiating plates Cl basal and brachydiagonal, almost equally perfect, fracture conchoidal or uneven H = 6 to 6 5 G = 2 6 to 2 67 Rarely transparent, vitreous, pearly on the cl Colourless, but generally white, grey, green, red, or yellow, streak white B B difficultly fusible, tinging the flame yellow, to a white semiopaque glass Not affected by acids C c 68 6 silica, 19 6 alumina with 0 1 to 1 iron peroxide, and 11 8 soda, with 0 3 to 4 lime, 0 to 2 5 potash Hence albite and orthoclase both contain soda and potash, only in different proportions Albite is most easily recognized by its frequent re entering angles, its readier fusibility, and the obliquity (93° 36) of its cl planes, often marked with striæ *Pericline* is a variety of which fig 533 is a typical form

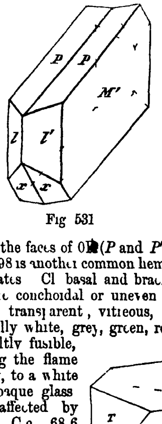


Fig 531

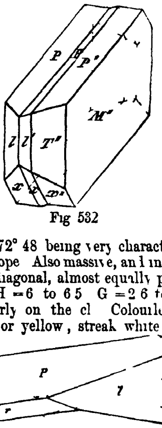


Fig 532

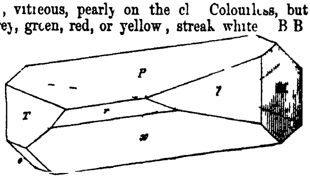


Fig 533

Albite is a constituent of many "greenstones," as at Corstorphine (Edinburgh), and of granite, syenite, gneiss, porphyry and trachyte. Crystallized at Murdoch s Cairn, Aberdeenshire being the colourless felspar of the red granites of Scotland Dauphine, St Gotthard, Tyrol, Salzburg, and Arendal

Adinole is a compact variety similar in appearance to *Leelite*

591 ANORTHITE, $\cancel{\mathrm{Al}}\mathrm{Si}+\dot{\mathrm{C}}\mathrm{aSi}$

Anorthic 0P (*P*) $\infty\breve{\mathrm{P}}\infty$ (*M*) 85° 50′, ∞P′ (*l*) ∞ P,(*T*) 120° 30 Hemitropes common on both *M* and *l* Angle between *P* and *P′* 180° 24 Cl basal and brachydiagonal, perfect H. = 6;

G = 2 7 to 2 78 Transparent or translucent, vitreous Colourless or white B B fuses to a clear glass, soluble without gelatinizing in con h acid C c 43 silica, 36 9 alumina 20 1 lime sometimes with magnesia and soda Fetlar in Shetland, Lendalfoot in Ayrshire, in gabbro Monte Somma, Iceland, Java *Lepolite* and *Amphodelite* are varieties In *Latrobite* the greater part of the lime is replaced by potash Glen Gairn and Labrador At both rose red

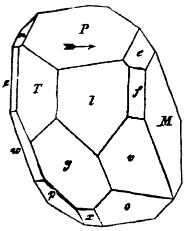


Fig 534

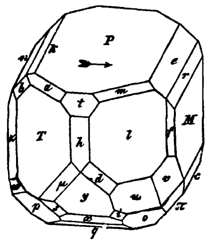


Fig 535

592 Oligoclase $2\bar{\text{Al}}\text{Si}_3+(\bar{\text{Na}}, \text{Ca})_2\text{Si}_3$

Anorthic 0P $\infty\breve{P}\infty$ 86° 10, ∞P ∞P 120° 42 Hemitropes face *m*, with *p p* 173° 4, *l l* 120° 20, *y y* 179° 9, *x x* 175° 59′. Cl basal, perfect, brachydiagonal, less so H = 6, G = 2 62 to 2 84 Vitreous, resinous on the cl White, with a tinge of green, grey, or red B B melts easier than orthoclase or albite to a clear glass, not affected by acids C c 63 silica, 23 4 alumina, 8 4 soda, and 4 2 lime thus nearly = 3 albite and 1 anorthite Distinguished from orthoclase by the marked striæ on the faces, less readily from albite, but more fusible and G higher The common associate of orthoclase in the Scotch grey granites, especially in vein granite, as at Rispond and Ben Loyal (figs 536, 537) in Sutherland, and at Rubislaw Scandinavia, Urals, Harz, and North America The *Sunstone*, from Foinaven in Sutherland, Norway, Lake Baikal, and Ceylon, with a play of colour due to imbedded crystals of rubinglimmer (gothite), belongs to this species

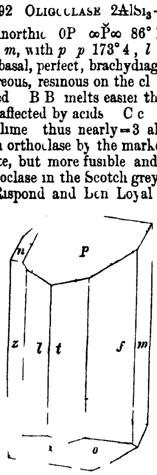


Fig 536

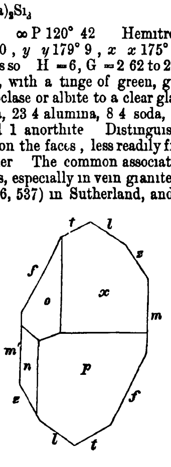


Fig 537

593 Labradorite, $\bar{\text{Al}}\text{Si}_3+(\text{Ca}, \bar{\text{Na}})\text{Si}$

Anorthic 0P $\infty\breve{P}\infty$ 86° 40, 0P ∞P 111° 0P $\infty P'$ 113° 34′, ∞P ∞P 121° 37, $\infty\breve{P}\infty$ ∞P 120° 53 $\infty\breve{P}\infty$ ∞P 117° 30′ Hemitropes of three types —(1) according to the first law of orthoclase as in fig 538, that is, vertical revolution and face of union $\infty\breve{P}\infty$, (2) revolution of one half with reunion on the face $\infty\breve{P}\infty$, as in fig 539, (3) with twin face P, as in fig 540 Hemitropes of the last form also occur in which the lower half consists of a hemitrope formed according to the second method Crystals imbedded in rocks consist generally of repeated twins affording an angle of 173° 20′ Cl basal, perfect, brachydiagonal, less so, both usually striated on account of the above twinning H = 6, G = 2 68 to 2 74 Translucent, vitreous, on the cl resinous Grey, passing into white, green, yellow, or red The faces of $\infty\breve{P}\infty$ often exhibit very beautiful changing colours—blue, green, yellow, red, or brown—sometimes bands intersecting at certain angles B B fuses more readily than orthoclase to a compact colourless glass Sol in h acid C c 52 9 silica, 30 3 alumina, 12 3 lime, and 4 5 soda It is thus = 1 albite and 3 anorthite Common constituent of dolerite, gabbro, and hypersthene rocks In Scotland, Labrador, Finland, Harz, Tyrol, also at Etna and Vesuvius

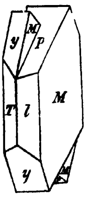


Fig 538

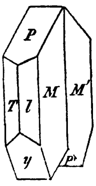


Fig 539

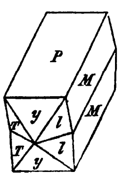


Fig 540

594 Andesine, $\bar{\text{Al}}\text{Si}_3+(\bar{\text{Na}}\text{Ca})\text{Si}$

Anorthic Crystals similar to albite and anorthite Twin face *M* Crystals generally formed of repeated plates G = 2 67 to 2 7 Physical properties like albite, more easily fusible to a porous white glass, h acid sometimes dissolves out alternate laminæ of crystals C c 59 7 silica, 25 6 alumina, 7 7 soda, and 7 lime, and thus nearly 1 of albite and 1 anorthite Typical of the primary limestones and a granitic belt therein in Scotland, as at Shinness, Urquhart, Dalnain, &c In the Andes, the Vosges, and Iceland

595 Hyalophane, $\bar{\text{Al}}\text{Si}_3$ $\bar{\text{K}}\text{Si}_3+\bar{\text{Al}}\text{Si}$, BaSi

Oblique prismatic resembles orthoclase crystals and angles nearly the same Cl 0P, perfect H = 6 to 6 5, G = 2 8 to 2 9 Transparent Lustre vitreous Colourless, white, and flesh-red C c silica 52 7, alumina 21, baryta 15 1, potash 7 8, soda 2 1 B B difficultly fusible to a blebby glass, not acted upon by acids Binnen in Valais, Jacobsberg in Sweden

596 Barsowite, $\bar{\text{Al}}\text{Si}+\text{CaSi}$

Right prismatic, or oblique prismatic H = 5 5 to 6, G = 2 58 Snow white, translucent Fracture granular Pearly C c silica 42 2, alumina 36 4, lime 19 8 Gelatinizes in h acid, difficultly fusible A dimorphic form of anorthite Barsovskoi in the Urals

597 Saussurite

A massive granular, translucent, white or pale green felspathic mineral of the nature of anorthite mixed with labradorite H = 6 to 7, G = 3 26 to 3 4 Probably a mixture Occurs in loose blocks near Geneva, and in Corsica In China and in India is carved under the name of Oriental jade (nephrite) Seems to be confounded also with zoizite, and perhaps with xu (prehnite) *Jadeite* is similar

Zeolite Group

These crystallize in all the systems except the anorthic, and themselves present great variety of development Mostly hyaline and white, rarely red, grey, or yellow Cl generally distinct All yield water in closed tube, all fusible B B most easily, and often intumescing, all sol in acids, and mostly gelatinize or deposit silica They are hydrated silicates of alkalies, or alkaline earths, mostly with silicates of alumina, but rarely contain magnesia Some mineralogists regard the water as basic, in union with silica, and Kenngott gives the formula in that form, thus —

Analcime, $(\dot{\bar{\text{Na}}}\bar{\text{Al}})\,2\text{Si}+2(\bar{\text{H}}, \text{Si})$,

Natrolite, $(\bar{\text{Na}}\bar{\text{Al}})\,2\text{Si}+2(\bar{\text{H}}, \text{Si})$,

Stilbite, $\text{Ca}, \bar{\text{Al}}+6(\dot{\bar{\text{H}}}, \text{Si})$,

and the others similar They are generally found in amygdaloidal cavities or fissures of trap or plutonic rocks, apparently as deposits from water percolating into them, and are thus probably products of decomposing nepheline or felspars, or hydrated felspars themselves They never form constituents of rocks Natrolite, scolezite, thomsonite, and the connected varieties are marked by their needle-like radiating forms, stilbite and heulandite by their broad, foliated, pearly cleavage

598 Pectolite, $4\dot{\text{Ca}}\text{Si}+\bar{\text{Na}}\text{Si}_2+\bar{\text{H}}$

Oblique prismatic, C 84° 37′ $\infty\bar{P}\infty$ (*c*), 0P (*u*) 95° 23′ Cl *c* and *u* Twin-face *c*, chiefly spheroidal and radiating fibrous H = 5, G = 2 74 to 2 88 Translucent, crystals pearly, fibres silky Pale green to yellowish white Sol in h acid, leaving silica C c 54 2 silica, 33 7 lime, 9 4 soda, and 2 7 water Ratho, Corstorphine, Castle Rock, and Arthur's Seat, Edinburgh, Kilsyth, Stirling, Knockdolian and Lendalfoot, Ayrshire, Skye, Montebaldo, Monzoni Valley in Tyrol

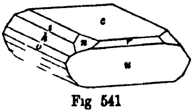


Fig 541

599 Walkerite, $4\dot{\text{Ca}}\text{Si}+\text{MgSi}+\bar{\text{Na}}\ddot{\text{Si}}_2+2\bar{\text{H}}$.

Like pectolite, but columnar H = 4 5, G = 2 7 Flesh-coloured Lustre pearly to greasy C c silica 53 7, lime 28 6, magnesia [illegible] 1, soda 7 9, water 4 6 Corstorphine Hill, Burntisland

600 Xonotlite, $4\dot{\text{Ca}}\text{Si}+\bar{\text{H}}$

Massive H = 6, G = 2 6 to 2 7 Pink, white, and grey Tough, fracture conchoidal and splintery C c silica 49 8, lime 43 5, protoxide of manganese 2 3, protoxide of iron 2 9, water 3 7 Kilfinichen and Torosay (Mull), Xonotla (Mexico)

601 Tobermorite, $3(\dot{C}a_4, \bar{H})Si_5 + 2\tfrac{1}{2}\bar{H}$

Massive, fine granular, translucent, fracture hackly H = 5, G = 2 4 Pale pink C c silica 49 8, lime 37 2, water 12 9 Tobermory (Mull), Dunvegan (Skye)

602 Okenite, $\dot{C}a\dot{\bar{H}}Si_2 + \bar{H}$

Right prismatic ∞P 122° 19 Usually fine fibrous, radiating H = 5, G = 2 28 to 2 36 Pellucid, slightly pearly Yellowish to bluish white In powder easily sol in h acid, leaving gelatinous flakes after ignition C c 56 6 silica, 28 4 lime, and 17 water, an apophyllite without the fluorine Disco Island, Faroes, and Iceland

603 Apophyllite, $8(CaSi + 2\dot{\bar{H}}) + KF$

Pyramidal P 120° 56 P, ∞P∞ (*m*), 0P (*o*), ∞P2 (*r*) Rarely lamellar Cl *o*, perfect Brittle H = 4 5 to 5, G = 2 3 to 3 4 Transparent, vitreous On *o* pearly (*Ichthyophthalmite*) Colourless, rarely pink, green, red, brown, and yellow B B exfoliates, intumesces, and melts to white enamel Sol in h. acid, leaving silica C c silica 50 3, lime 24 7, water 15 9, potassium 4 3, fluorine 2 1 Dunvegan and Storr, Skye (fig 544), Chapel, Fife Corstorphine (fig 542) and Ratho, near Edinburgh, Kilsyth, Bowling, Kilpatrick, Port Rush, Ireland In the form P (fig 79), grass green at Oxhaveer, Iceland (*Oxhaveerite*), Uto, Sweden, Andreasberg and Faroes (pink), Faroes, and Poonah in India (green) Internal structure tesselated, being built up of wedge and lenticular forms with varying refractive indices, hence exhibiting a beautiful structure with polarized light

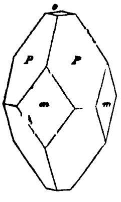


Fig 542

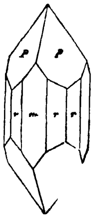


Fig 543

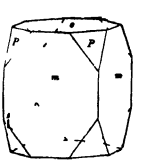


Fig 544

604 Gyrolite, $(\tfrac{2}{3}Ca + \tfrac{1}{3}\dot{\bar{H}})Si + \bar{H}$

Lamellar, radiate, spherical, and investing H = 3 to 4 Pearly Bluish white to cream coloured Transparent, rapidly becoming opaque C c silica 53 3, lime 32 9, water 13 8 Quiraing, Lyndale, and Storr, Skye, Loch Screden and Carsaig, Mull, Canna, Karartut, Niakornak, and Disco, Faroes, Nova Scotia

605 Analcime, $\bar{Al}Si_3 + \dot{N}aSi + 2\bar{H}$

Cubic ∞O∞, 2O2 Fracture uneven H = 5 5, G = 2 1 to 2 28 Colourless, white, flesh red, scarlet Vitreous, transparent B B melts without frothing to a clear vesicular glass Decomposable with gelatinization in h acid C c 54 5 silica, 23 3 alumina, 14 1 soda, 8 2 water Walls, Orkney, Talisker, Skye, Sanda, and Hebrides generally Transparent at Eigg, and Elie, Fife, scarlet at Bowdens, Kincardine, opaque white at Glen Farg, Salisbury Crags, and Dumbarton, Giant s Causeway, Seisser Alp in Tyrol, Cyclopean Islands (fig 545), Faroes, Iceland, and Nova Scotia *Eudnophite* is a variety Pectolite (sp 598) occurs pseudomorphous after analcime, in large crystals of *a*, *n*, at Ratho, Edinburghshire

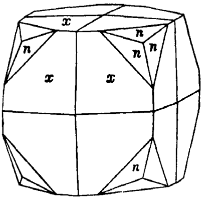


Fig 545

606 Pollux, $3(\bar{Al}Si_3 + (\dot{C}s_{\frac{2}{3}}, \dot{N}a_{\frac{1}{3}})Si) + 2\bar{H}$

Cubic ∞O∞, 2O2 (fig 546) Also massive Gum like externally Brittle, with traces of cleavage Fracture conchoidal H = 5 5 to 6 5, G = 2 86 to 2 9 Colourless Vitreous Sol in h acid C c silica 44, alumina 16, oxide of cæsium 34, soda 2 5, water 2 4. Elba. The only mineral which contains cæsium in quantity.

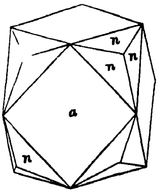


Fig 546 (sp 606)

607 Faujasite, $2\bar{Al}Si_3 + (\dot{C}a\dot{N}a)_2Si_3 + 18\bar{H}$

Cubic, in octahedrons with the icositetrahedron $3O3$ Fracture uneven, brittle H = 7, G = 1 92 Transparent, vitreous to adamantine White to brown Sol in h acid C c 46 8 silica, 16 alumina, 4 4 lime, 4 8 soda, 28 water Kaiserstuhl in Baden, Annerod near Giessen, Eisenach, Marburg

608 Chabasite (*Lime Chabasite*), $\bar{Al}Si_3 + CaSi + 6\bar{H}$

Rhombohedral, R 94° 46′ $\tfrac{1}{4}\tfrac{3}{5}R\tfrac{4}{5}$, −½R (*r*), −2R (*e*), ∞P2 (*a*) Twins very common (generally intersecting) on faces ∞P and $\breve{P}\infty$ Primary rhombohedron is sometimes twinned with a crystal with faces *r*, *e*, *s* Cl *r* perfect H = 4 to 4 5, G = 2 to 2 2 Transparent or translucent, vitreous Colourless, and brownish, yellowish, brick, and flesh red Sol in h acid, leaving silica. C c silica 47 8, alumina 20 8, lime 10 7, water 21 3 Lyndale (figs 547, 548, 549), Talisker (figs 176, 550, sometimes flesh colour), and Storr, Skye (figs 547, 548), Port Glasgow and Kilmalcolm (pink and brown), Giant's Causeway and Magee Island (red), Faroes, Iceland, Aussig, Andreasberg (fig 551) *Haydenite* in twinned rhombohedra, with *p* *p* 95° to 97° and *p* *d* 170° reentering (fig 552), from Fassa and Maryland, is similar *Phacolite* is chabasite in twins of ⅔P2, ∞P2, R, −½R at the Giant's Causeway (fig 154) At Richmond in Victoria they occur as in fig 553, −2R (*n*), −⅔R (*r*), ⅔P2 (*t*), 0P (*c*), polar edge ⅔P2 145° In this, half of the lime is replaced by soda.

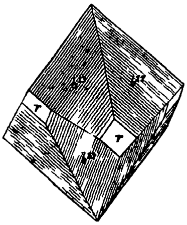


Fig 547

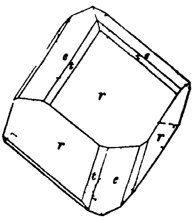


Fig 548

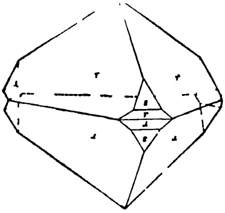


Fig 549

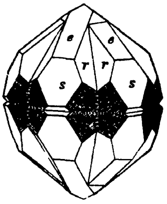


Fig 550

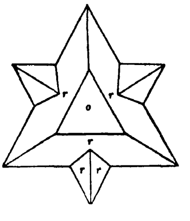


Fig 551

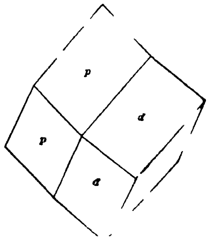


Fig 552

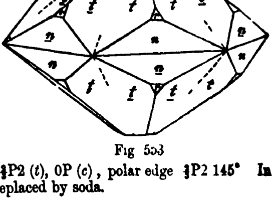


Fig 553

609 Gmelinite (*Soda-Chabasite*), $\bar{Al}Si_3 + \dot{N}aSi + 6\bar{H}$

Hexagonal R 112° 26′, P 79° 54′ Combination P, 0P ∞P (figs 554 556) *Faces of P striated parallel to the polar edge those* of the prism horizontally (fig 55 Cl ∞P distinct Gelatinizes with h acid C c 47 6 silica 19 7 alumina 12 soda 20 7 water Certain crystals seem to indicate twinning Talisker in Skye (twins of fig 555) Glenarm in Antrim (fig 555) Vicenza Pyrgo in Cyprus Cape Blomidon in Nova Scotia

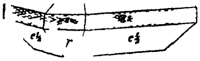


Fig 554

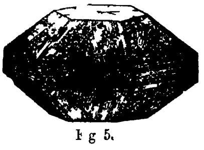


Fig 555

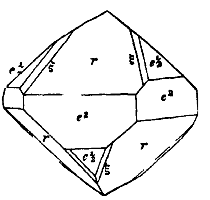


Fig 556

610 LEVYNE $\text{AlSi} + \text{CaSi} +$ H5

Rhombohedral R (*s*) 79° 29, ½R (*r*) 106 3 0R (*o*) Forms intersecting twins as in fig 557 H 4 G = 2 1 to 2 2 Colourless and white C c silica 43 8 alumina 23 8 lime 9 7 water 21 Storr in Skye (*o s*) Ireland (at Glenarm Island Magee Londonderry &c) Iceland Dalsnypen and Naalsoe in the Faroes

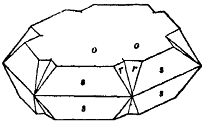


Fig 557

611 HERSCHELLITE $(\text{CaNa})\text{Si} + 5\text{H}$

Hexagonal prisms (*e*) surmounted by two trihedral pyramids of and one of *a* (fig 558) *a* *e* 122 8 a^{11}_{5} *e* 107 26 *e* striated horizontally Cl *e* fracture conchoidal transparent vitreous White or colourless H 5 5 G = 2 06 C c silica 47 alumina 21 2 lime 5 2 soda 4 8 potash 2 water 17 86 Aci Castello and Palagonia in Sicily Yarra in Australia

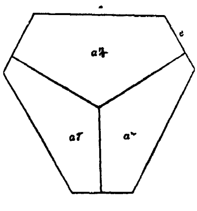


Fig 558 (sp 611)

612 LAUMONTITE (*Leonhardite*) $\text{AlSi}_3 + \text{CaSi} + 4\text{H}$

Oblique prismatic C 80 42 ∞P ( ) 86 16 ∞P – ∞P̄ (*e*) 113 30 P∞ ∞P 111 14 *e* *a* 125 41 *a* *b* 90 *e* 145 15 Twin face *a* Cl *m* perfect very brittle H = 3 to 3 5 G = 2 2 to 2 3 Pellucid when fresh vitreous pearly on cl White cream coloured brick red De composes rapidly through loss of water B B intumesces and melts first to a white enamel ultimately to a clear glass Gelatinizes in h acid C c silica 50 9 alumina 21 8 lime 11 9 water 16 3 Rapidly loses 1 equivalent or 3 86 per cent of water and becomes friable (*Hypostilbite*) Kilfinichen, Mull (fig 559) Storr and Quiraing Skye (hypostilbite) Tod Head Snizort Glen Farg (red) Bowling Dumbarton (twins of *m e*) Huelgoat in Brittany Prague Falun Iceland Faroes Nova Scotia *Caporcianite* from Tuscany has only 3 water

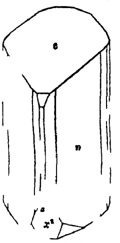


Fig 559

613 EPISTILBITE (*Reissite*) $\text{AlSi}_3 + \text{CaSi}_3$ 5H

Oblique prismatic C 54 53 ∞P (*m*) 135 10 P∞ (*t*) 109 46 ½P(*s* 14 40 fig 560) Hemitropes united by *m* with twins of the same united by the brachydiagonal (*a*) Cl brachydiagonal perfect H = 3 5 to 4 G = 2 3 to 2 4 Pellucid vitreous pearly on cl Colourless Sol without gelatinizing C c silica 59 alumina 17 5 lime 9 soda 1 5 water 14 5 Talisker in Skye (*m t o*) Hartlepool (in twins) Iceland Faroes Silesia Viesch in Valais, Nova Scotia and New Jersey

Fig 560

614 *HEULANDITE* $\text{AlSi}_3 + \dot{\text{C}}\text{aSi}_3 + 5\text{H}$

Oblique prismatic C 63° 40 P°∞ (*p*) 50° 20 2P (*z*) ⅔P (*u*), 2P°∞ (*r*) 3P°∞ (*s*) ∞P̄∞ ∞P°, 0P *z* *z* 136° 4, *u* *u* 146° 52 Crystals elongated along each of the axes present very varying forms but generally tabular Cl clinodiagonal, perfect pearly on this vitreous on others brittle H = 3 5 to 4 G = 2 1 to 2 2 Transparent to translucent colourless, white brick red rose green hair brown B B melts with exfoliation and intumescence to a white enamel Sol in h acid leaving silica Storr and Talisker Skye (fig 562) Sanda Kilmalcolm Catterline Kincardine (fig 563) Kilpatrick Hills (*p m n r s*) and Kintyre (red) Iceland Faroes Fassa Valley Nova Scotia Baltimore (*Beaumontite*) (fig 565) (*p m n t*) Vindhya Mountains in India (fig 564)

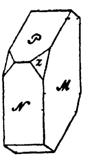


Fig 561

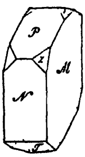


Fig 562

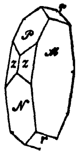


Fig 563

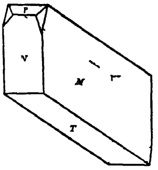


Fig 564

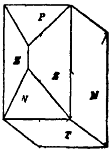


Fig 565

615 BREWSTERITE $\text{AlSi}_3 + \text{RSi}_3 + 5\text{H}$ R = (⅘Sr + ⅖Ba + ⅕Ca)

Oblique prismatic C 86 56 ∞P°∞ (*a*) ∞P°∞ (*l*) 0P (*o*), *n*P°∞ (*e*) ∞P (*m*) ∞P°2 (*c*) ∞P°½ (*t*) *e* *e* 173 10 (fig 566) Cl clinodiagonal perfect pearly on do vitreous on others pellucid H 5 to 5 5 G = 2 5 to 2 45 Colourless yellow or brown Sol with gelatinization in h acid C c 54 3 silica 15 alumina 9 strontia 6 6 baryta 1 3 lime 13 5 water Strontian Freiburg in the Breisgau Pyrenees

Fig 566 (sp 615)

616 PHILLIPSITE $\text{AlSi}_3 + (\text{Ca K})\text{Si} + 5\text{H}$

Oblique prismatic C 55 1 ∞P (*m*) ∞P°∞ (*b*) 0P (*c*) Polar edges 120 42 and 119 18 Faces *b* and *m* striated parallel to the intersections Apparently always twinned generally these duplicated by intersection on face *b* or face *c* (figs 567 568) and frequently arranged so that three of the above double twins intersect at right angles to one another forming the cruciform fig 569

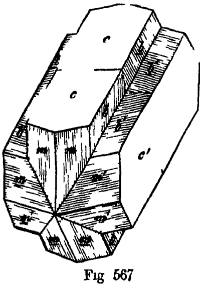


Fig 567

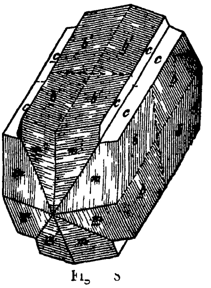


Fig 568

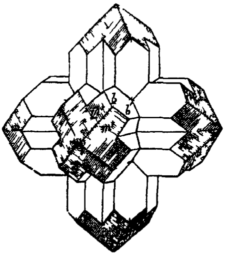


Fig 569

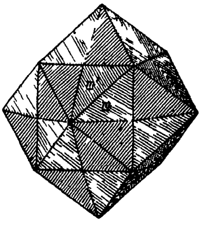


Fig 570

When the prismatic faces of these are short the faces *m* of the intersecting individuals fall nearly into one plane presenting the form fig 570 when long fig 190 Brittle fracture uneven H = 4 5, G = 2 15 to 2 2 Gelatinizes in h acid C c silica 48 6 alumina 20 2 lime 7 3 potash 6 2 water 17 7 Giant s Causeway, Giessen, Marburg Cassel Capo di Bove Vesuvius, Iceland

617 Harmotome $\mathrm{AlSi_3 + BaSi_2 + 5H}$

Oblique prismatic C 55° 10 ∞P (*s*) ∞P ∞ (*b*) 0P (*a*) Forms like phillipsite but more frequently in simple twins Physical properties like phillipsite but G 2 3 to 2 5 and fuses with difficulty Difficultly sol in h acid C c 46 5 silica 15 9 alumina 23 7 baryta and 13 9 water Strontian transparent (*Morvenite* fig 5 2 and opaque (figs 571 573) Glen Arbuel (fig 574) and Bowling in Dumbarton Corstorphine near Edinburgh Andreasberg Kongsberg Oberstein

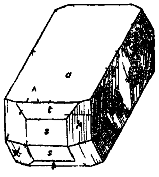


Fig 571

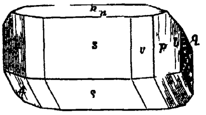


Fig 572

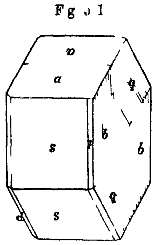


Fig 573

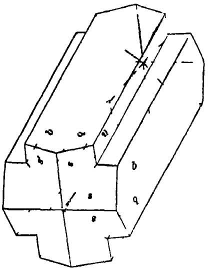


Fig 574

618 Stilbite $\mathrm{AlSi_3 + CaSi_3 + 6H}$

Oblique prismatic but with right prismatic habit C 50° 49 ∞P∞ (*a*) ∞P̄∞ (*b* P (*r*) ∞P2 (*m*) 0P (*p*) Cl *a* perfect H = 3 5 to 4 G 2 1 to 2 2 Transparent vitreous Pearly on *a* Colourless white yellow pale brown, brick red Decomposed by h acid leaving silica C c silica 57 5 alumina 16 4 lime 8 9 water 17 2 Storr and Talisker in Skye (*a b p* (fig 575) and in Hebrides (colourless) Arran and Kilmalcolm (pale brown) Long Craig (Dumbarton) and Kinneff Kincardine) (brick red) Iceland Faroes Andreasberg Vindhya Mountains Wellington Mountains (Australia Nova Scotia

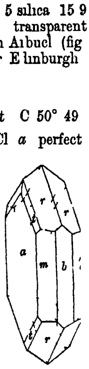


Fig 575 (sp 618

619 Pufflerite $\mathrm{AlSi_3 + CaSi_3 + 5H}$

Fibrous globular concretions with vitreous surface H = 4 G = 2 21 Greyish white Transparent C c silica 52 8 alumina 16 3 lime 11 ? water 17 2 Pufflatsch in the Seisser Alp

620 Edingtonite $\mathrm{4AlSi + 3BaSi + 12H}$

Pyramidal hemihedral with inclined faces P 87° 19 ½P (*n*) 129° 8 ∞P (*a*) polar edges P 92° 51 (fig 576) Cl *a* perfect fracture uneven H 4 to 4 5 G = 2 7 to 2 71 Translucent vitreous Colourless C c silica 37 3 alumina 23 75 baryta 26 52 water 12 46 Kilpatrick Hills in Dumbartonshire

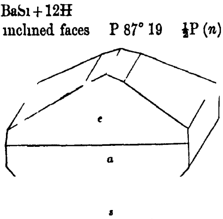


Fig 576 (sp 620)

621 Forresite $\mathrm{2AlSi + (Na, Ca_3)Si_6 + 6H}$

Right prismatic ∞P̄∞ ∞P∞ , 0P Cl brachydiagonal perfect, lustre thereon pearly G = 2 4 White C c silica 50 alumina 27 4 lime 5 5 soda 1 4, water 15 1 San Piero in Elba

622 Natrolite $\mathrm{AlSi_2 + NaSi + 2H}$

Right prismatic ∞P (*m*) 91° P (*o*) polar edges 143° 20 and 144° 40, middle edge 53° 20 ∞P̌∞ (*b*) ∞P̄∞ (*a*) Radiating acicular crystals often fibrous Cl ∞P, perfect H = 5 to 5 5, *G = 2 17 to 2 26 Pellucid*, *vitreous* Colourless ochre yellow, reddish Is not pyro electric B B melts quietly to a clear glass, colouring flame yellow Sol in oxalic acid C c 47 2 silica 27 alumina 16 3 soda 9 4 water Glen Farg (fig 577) (colourless and reddish) Tantallon Castle (fig 578) Dumbarton Bowling (green) Campsie Bishopton Glenarm and Port Rush (Ireland) Auvergne Hesse Hohentwiel in Swabia Norway *Crocalite* is red fibrous and investing Kintyre Forfarshire Wemyss Bay and the Urals

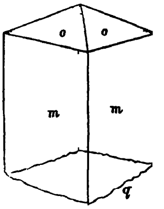


Fig 577

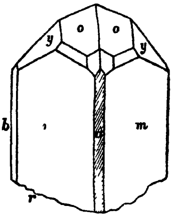


Fig 5 8

623 Scolecite $\mathrm{AlSi_2 + CaSi + 3H}$

Oblique prismatic C 89° 6 ∞P (*m*) 91 35 1 (*o*) 144° 20 P Prismatic and acicular crystals Twins common on face ∞P̊∞ one face with feathered striæ Cl ∞P perfect H = 5 to 5 5 G 2 2 to 2 3 Pellucid vitreous pyro electric White to reddish white B B twists in a vermicular manner melting readily to a porous glass Only partially sol in oxalic acid C c silica 45 8 alumina 26 2 lime 14 3 water 13 7 Staffa Loch Screden Mull Talisker Skye Berufiord Iceland (fig 579) Faroes Vindhyas India Natrolite and scolecite pass into one another There are two definite intermediates—*Farg te* consisting of two equivalents of natrolite and one of scolecite and *Mesolite* consisting of one of the former and two of the latter The first of these occurs at Glen Farg and at Bishopton (*Galactite*) the second is the ordinary radiated zeolite of the amygdaloids of the Tertiary igneous rocks of the Hebrides and the Faroes It there occurs in matted crystals of extreme tenuity (*Cotton stone*) also in delicate feathery tufts in Renfrewshire in spheres with an internally radiated structure and also in needle form and in downy tufts

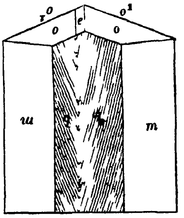


Fig 5 9

624 Gismondine $\mathrm{AlSi + CaSi + 4H}$

Pyramidal 1 (*b*) 92 30 polar angle 118° 34 ∞P∞ (fig 580) Cl P H 5 on edges and angles 5 to 6 G 26 Translucent vitreous Bluish white to pale red C c silica 35 9 alumina 27 3 lime 13 1 potash 2 8 water 21 1 Island Magee and Larne Ireland Vesuvius Aci Castello and Capo di Bove Schiffenberg near Giessen Schlauroth near Gorlitz

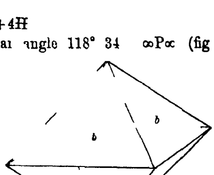


Fig 580

625 Zeagonite $\mathrm{AlSi + (CaK)Si + 4H}$

Right prismatic P polar angle 120° 37 and 121° 44 middle angle 89° 13 Crystals like fig 419 H = 5 on edges and angles 7 G = 2 2 Transparent vitreous Colourless white or bluish C c silica 44 alumina 23 3 lime 5 3 potash 11 1 water 15 3 Capo di Bove

626 Thomsonite $\mathrm{2AlSi + 2(CaNa)Si + 5H}$

Right prismatic ∞P (*m*) 90° 26 ∞P̄∞ (*a*) ∞P̌∞ (*b*) ½P∞ (*y*) P̄∞ (*r*) $\frac{1}{48}$P̌∞ (*x*) *x x* 177° 34 20 Cl macrodiagonal and brachydiagonal both perfect H to 5 5 G = 2 35 to 2 38 Translucent vitreous pearly on macrodiagonal Colourless B B difficultly fusible with intumescence to a white enamel Sol with gelatinization in h acid C c silica 38 7 alumina 30 8 lime 13 4, soda 4 4 water 13 1 Lochwinnoch, Renfrew, Kilpatrick (fig 582) Quiraing and Talisker (sometimes

Fig 581 (sp 626)

massive granular), Rathlin and Magee Island, Ireland, Faroes, Vesuvius (fig 581) Sicily, Bohemia, Tyrol, Nova Scotia

Faroelite is a variety with 42 5 of silica It replaces thomsonite generally in Tertiary igneous rocks, occurring at Storr and elsewhere in the Hebrides, Faroes, Iceland and Nova Scotia The angle of the vertical prism is within 8 of that of thomsonite It contains an equivalent more silica

627 Prehnite, $\bar{A}lSi + 2CaSi + \dot{H}$

Right prismatic ∞P (*m*)

Fig 582 (sp 626)

(*c*) $3\breve{P}\infty$ (*e*) 33° 26 , $\frac{3}{4}\bar{P}\infty$ (*v*) 90° 32 , ((*a*), $\infty\bar{P}\infty$ (*b*), P (*s*) Crystals either tabular of *c*, or prismatic along both the vertical and the brachydiagonal axes, hence varying much in form Also in fan shaped and botryoidal aggregations Cl (perfect, pearly thereon, vitreous elsewhere H = 6 to 7, G = 2 8 to 3 Transparent to translucent Colour

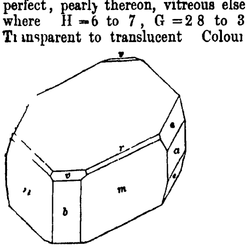


Fig 583

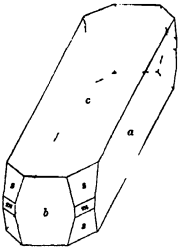


Fig 584

melting to a porous enamel Decomposed by h acid C c silica 43 6, alumina 24 9, lime 27 1, water 4 4 Glen Gairn, Aberdeen (fig 583) Skye and Mull Corstorphine Hill (green and pink), Castle Rock (white) and Salisbury Crags (yellow) Edinburgh, Frisky Hall, Dumbartonshire (fig 584) Hartfield Moss, Renfrew (botryoidal), Cornwall, Dauphiné Tyrol Cape of Good Hope, China (*Yu*)

628 Friedelite, $Mn_4Si_3 + 2\bar{H}$

Rhombohedral, R 123° 42 0R, ∞R Tabular habit, and in granular aggregates Cl basal, perfect H = 4 to 5, G = 3 1 Rose red, with paler streak C c silica 36, protoxide of manganese 53, lime 2 96, water 7 9 Adervielle on the Neste de Louron (Pyrenees)

Hydrous Silicates of Alumina

These are probably for the most part products of decomposition of felspars under atmospheric exposure

629 Kaolin (*Porcelain Earth*), $\bar{A}lSi_2 + 2\bar{H}$

Massive, in beds and veins Fracture uneven fine earthy, very soft, sectile, and friable H = 1, G = 2 2 Opaque, dull White or grey, inclining to blue, green, yellow, or red Feels meagre, not greasy when dry, and plastic when wet B B infusible Not affected by h acid, but decomposed by warm s acid leaving silica C c very variable, but approximates to 46 silica, 40 alumina, and 14 water Chiefly a product of the decomposition of orthoclase or of granite, porphyry, and other rocks containing that mineral Cornwall and Devonshire in England are the chief European localities for the kaolin used in manufacturing porcelain

Clays are merely varieties of kaolin, mixed with quartz sand, carbonate of lime, magnesia, and the oxyhydrates of iron Often 40 to 50 silica, 30 alumina, 13 to 20 water, and 4 iron peroxide, with lime and potash In the fire they are infusible, burning hard Generally they are compact and friable, of white, yellow, red, blue grey or brown colours Their specific gravity varies from 1 8 to 2 7 The following are varieties *Pipe clay*, greyish or yellowish white, with a greasy feel, adheres strongly to the tongue, when wet is very plastic and tenacious, and in the fire burns white Abundant in Devonshire and in the Trough of Poole in Dorsetshire, in France Belgium, and Germany Used for manufacturing tobacco pipes and similar articles *Potter's Clay*, red, yellow, green, or blue, b oming yellow or red when burnt, more easily fused than the former, and often effervesces with acids That used in the potteries in England comes chiefly from Devonshire *Loam*, coarser and more impure, with more sand, and consequently less plastic *Shale* or *Slate Clay*, greyish black, and much mixed with bituminous or carbonaceous matter *Bituminous Shale*, known by its shining resinous streak *Black Chalk*, with more carbon, leaves a black mark on paper *Iron Clay* contains much peroxide of iron, is reddish brown, and forms the basis of many amygdaloids and porphyries

630 Nacrite, $\bar{A}lSi_2 + 2\bar{H}$

Right prismatic, minute six sided tables in fan like group, and scaly H = 0 5 to 1, G = 2 35 to 2 6 Glimmering to pearly, snow white or yellowish white C c silica 46 3, alumina 39 8, water 13 9 A crystalline form of kaolin Fins in Allier, Mons, Freiberg, Pennsylvania, and coal formation commonly

631 Lithomarge

Kaolinic substances, compact, earthy, and pseudomorphous H = 2 5 to 3, G = 2 4 to 2 6 White, yellow, or red Greasy, adheres to tongue Klausthal, Harz, &c Similar are *Carnat*, *Myclin*, *Melopsite*

632 Halloysite, $\bar{A}lSi + 4\bar{H}$

Massive and reniform H = 1 5 to 2 5, G = 1 9 to 2 1 Translucent when moist Bluish white, green, or yellow C c 41 5 silica, 34 4 alumina, 24 1 water Hospital Quarry near Elgin, on the Tweed, Liege, Tarnowitz, Eifel (*Lenzinite*) *Fuller's Earth* may be an impure ferruginous variety Maxton in Scotland, Reigate and Maidstone in England, Saxony, Bohemia, &c

633 Glagerite, $Al_2Si_3 + 6\bar{H}$

H = 1, G = 2 35 Bergnersreuth *Malthazite*, from Steindorfel near Bautzen, has less alumina

634 Kollyrite, $Al_2Si + 9\bar{H}$

H = 1 to 2, G = 2 Also similar Schemnitz, Pyrenees, and Saxony *Scarbroite* from Scarborough has $10H_2O$

635 Miloschin

Conchoidal or earthy H = 2, G = 2 1 Indigo blue to celadon green, has 2 to 4 chrome oxide Rudnik in Servia

636 Montmorillonite, $Al_2Si_7 + 2\bar{H}$

Massive Rose red Montmorillon and elsewhere in France, Podurnoj in Transylvania

637 Razoumoffskin, $\bar{A}lSi_3 + 3\bar{H}$

From Carinthia *Chrome Ochre*, with 2 to 10 per cent of chrome oxide, from Waldenburg in Silesia and Creusot in France, is similar

638 Cimolite, $Al_2Si_9 + 6\bar{H}$

Pseudomorphous after augite Bilin, Limburg, Kaiserstuhl, Argentiera and Milo

639 Allophane, $\bar{A}lSi + 5\bar{H}$

Botryoidal and reniform Fracture conchoidal, brittle H = 3, G = 1 8 to 2 Pellucid, vitreous Pale blue white, green, or brown Colour due to copper Charlton, Woolwich, Baden, and Bonn

640 Pyrophyllite, $\bar{A}lSi_4 + \dot{H}$

Right prismatic, but radiated, foliated Cl perfect, flexible, sectile H = 1, G = 2 8 to 2 9 Translucent, pearly Light verdigris green to yellowish white B B swells up with many twistings to a white infusible mass C c 67 silica, 28 alumina, and 5 water Urals, Spa, Morbihan, Westana in Sweden, Carolina, and Brazil *Talcosite*, from Heathcote in Victoria, has silica and alumina about equal

641 Anauxite, $\bar{A}lSi_4 + 3\bar{H}$

Granular H = 2 to 3, G = 2 2 to 2 4 Translucent, pearly Greenish white C c 60 5 silica, 26 alumina and 13 5 water Bilin in Bohemia

Hydrous Silicates of Zirconia, Thoria, &c

642 Malacone, $3ZrSi + \bar{H}$

Pyramidal P 83° 30′ Typical form ∞P∞, P, ∞P H = 6, G = 3 9 to 4 1 Conchoidal fracture Lustre vitreous C c same as zircon, but with 3 of water in the Hittero variety and over 9 in that from Finland Has a surface opalescence and may be altered zircon Hittero, Chanteloube (near Limoges), near Dresden, Rosendal, Finland, Miask

643 Eucrasite

Right prismatic (?) H = 4 5 to 5, G = 4 39 Lustre greasy Blackish brown, streak brown Translucent on edges Fracture uneven brittle C c very complex silica 16 thoria 36 cerium

[illegible]

near Brevig

644 Thorite, $ThSi + 2\bar{H}$

Pyramidal ∞P P 133° 30 Generally massive H = 4 5 to 5. G = 5 to 5 4 Lustre brilliant vitreous, when weathered resinous Fracture conchoidal when fresh, splintery when weathered Brownish black to clove brown C c complex, but essentially 18 silica, 73 thoria, 9 water In syenite at Lochan

Hacon, and in a boulder on Ben Bhreck in Sutherland, in crystals (fig 585), Lowo near Brevig, Norway *Uranothorite*, from Arendal has 50 per cent thoria and 10 uranous oxide, found also at Hitterö and at Champlain (U S)

645 ORANGITE, $3\mathrm{ThSi} + 2\bar{\mathrm{H}}$

Massive Orange yellow to cinnamon red Other characters like thorite C c 17 silica, 75 thoria 7 water Ben Bhreck, Langesund near Brevig The mineral from Ben Bhreck passes gradually into thorite, which thus would appear to be altered orangite

646 TRITOMITE, $\bar{\mathrm{R}}_2\mathrm{Si}_3 + 4\bar{\mathrm{H}}$

Cubic In tetrahedra H = 5 5, G = 3 9 to 4 66 Lustre vitreous Dull brown, streak yellowish grey Subtranslucent C c complex silica 21, alumina 2 5, ceria 40, lanthana 1 5 yttria 4 6, lime 4 water 8 Lamo near Brevig

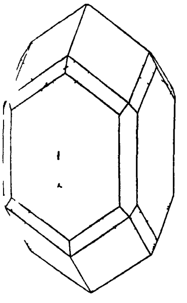


Fig 585 (sp 644)

MAGNESIAN SILICATES

647 AGALMATOLITE (*Figure Stone*), $4\bar{\mathrm{Al}}\mathrm{Si} + \bar{\mathrm{K}}\mathrm{Si}_3 + 3\bar{\mathrm{H}}$

Massive or slaty Fracture splintery, rather sectile H = 2 to 3, G = 2 8 to 2 9 Translucent glimmering Green grey, red, and yellow Feels somewhat greasy, but does not adhere to the tongue Sol in s acid C c 55 silica, 33 alumina, 7 6 potash and 5 water, but in many localities magnesian Calligaig in Sutherland China, where it is cut into various works of art, also Nagyag in Hungary, and Saxony

648 ONCOSIN, $2\bar{\mathrm{Al}}\mathrm{Si}_2 + (\bar{\mathrm{K}}\ \mathrm{Mg}\ \mathrm{Si} + 2\bar{\mathrm{H}}$

Fracture uneven or splintery sectile H = 2, G = 2 8 Translucent, slightly resinous Apple green or brown Sol in s not in h acid Salzburg

649 LIEBENERITE

Hexagonal ∞P, 0P Cl prismatic, perfect, fracture hackly H = 3 5, G = 2 8 Oil green, bluish green, and greenish grey Greasy lustre C c silica 44 7, alumina 36 5, potash 9 9, water 5 5 Monte Viesena near Forno, Predazzo in Tyrol

650 GIESECKITE

Hexagonal ∞P, 0P Fracture splintery H = 3 to 3 5, G = 2 7 to 2 9 Kangerdluarsuk in Greenland, Diana in New York

651 KILLINITE, $2\bar{\mathrm{Al}}\mathrm{Si} + \mathrm{RSi}_2 + 3\bar{\mathrm{H}}$

Crystalline, foliated Cl along a prism of 135° 44 G = 2 65 Greenish grey, yellow, or brownish green C c 48 silica, 31 alumina, 2 3 protoxide of iron, 6 5 potash, 10 water Killiney near Dublin

652 HYGROPHILITE

Scaly H = 2 to 2 5, G = 2 7 Greenish grey Lustre and feel greasy C c silica 48 4, alumina 32 1, protoxide of iron 3 3, potash 5 7, water 9 Sol in h acid Halle on the Saale

653 BRAVAISITE, $\mathrm{R\,Si}_3 + 2\bar{\mathrm{Al}}\mathrm{Si}_3 + 4\bar{\mathrm{H}}$

Aggregates of thin plates H = 1 to 2, G = 2 6 C c silica 51 4, alumina 18 9, peroxide of iron 4, magnesia 3 3, potash 6 5, water 13 3 Noyant in Allier

654 PINITOID

Massive Leek and oil green H = 2 5 G = 2 8 C c silica 48 5, alumina 28, protoxide of iron 8, potash 5 8, water 4 5 Freiberg and Chemnitz in Saxony

655 BOLE

Earthy, in nests and veins Conchoidal H = 1 to 2, G = 2 2 to 2 5 Opaque, dull resinous, streak shining Brown, yellow, or red Feels greasy, some adhere strongly to the tongue, others not at all In water crackles and falls to pieces C c hydrous silicates of alumina and iron peroxide, in various proportions Scotland, Ireland, Dransfeld, Clermont in Auvergne *Stolpenite*, *Rock Soap*, *Plinthite*, *Yellow Earth* or *Felinite*, *Fetbol*, and *Ochran* are varieties

656 CARPHOLITE, $\dot{\bar{\mathrm{Al}}}\mathrm{Si} + \mathrm{MnSi} + 2\dot{\bar{\mathrm{H}}}$

Right prismatic P 111°27′ Radiating stellated H = 5 to 5 5, G = 2 9 Translucent, silky, straw to wax yellow B B intumesces and fuses to an opaque brown glass C c silica 38, alumina 29 4, protoxide of iron 2 9, peroxide of iron 4, protoxide of manganese 11 8, water 10 8 Schlaggenwald, Wippra in the Harz, Meuville in the Ardennes

657 NONTRONITE, $\bar{\mathrm{Fe}}\mathrm{Si}_3 + 5\bar{\mathrm{H}}$

Massive, fracture uneven H = 2 to 3, G = 2 to 2 3 Opaque, dull or glimmering, streak resinous Straw yellow or siskin green. B B decrepitates, becomes black and magnetic, but without fusing, sol and gelatinizes in warm acids C c 43 silica, 36 iron peroxide and 21 water, with 3 5 alumina and 2 magnesia Nontron in France, Harz, and Bavaria *Chloropal* is similar B B brown Unghvar in Hungary, and Passau

658 PINGUITE

Massive, fracture splintery, sectile H = 1, G = 2 3 Light to dark green Lustre vitreous Feels greasy C c silica 36 9, peroxide of iron 29 5, protoxide of iron 6 1, water 25 1 Wolkenstein Suhl

659 HISINGERITE, $\bar{\mathrm{Fe}}_2\mathrm{Si}_3 + 2\mathrm{FeSi} + 9\bar{\mathrm{H}}$

Reniform, and in crusts H = 3 5 to 4, G = 2 6 to 3 Opaque resinous Brownish or bluish black, streak liver brown or yellowish brown C c various, but 32 5 silica, 33 5 iron peroxide, 15 1 iron protoxide, and 19 water, in the *Thraulite* from Bodenmais Also Gilling and Riddarhyttan in Sweden, and Breitenbrunn (*Polyhydrite*)

660 BERGHOLZ

Fine fibrous glimmering lustre Wood brown to green G = 2 4 C c silica 55 5, peroxide of iron 19 5, magnesia 15, water 10 3 Sterzing in Tyrol *Xylite*, probably from the Urals, is similar

661 UMBER

Massive, fracture conchoidal H = 1 5, G = 2 2 Liver brown, streak shining Mixtures of peroxide of iron, oxide of manganese, and alumina with water Cyprus *Hypoxanthite* and *Siderosilicite* are similar

662 KLIPSTEINITE, $(\mathrm{R}_3\ \bar{\mathrm{R}}_3)\,\mathrm{Si}_3 + \mathrm{R}_3\bar{\mathrm{H}}_3$

Compact H = 5 to 5 5, G = 3 5 Liver brown to black, streak yellow brown C c silica 25, peroxide of iron 4, sesquioxide of manganese 57, water 9 Klapperud in Dalecarlia, Herborn near Dillenburg

663 WOLKONSKOITE

Amorphous Horny, bluish green to grass green Fracture conchoidal, brittle C c silica 36 alumina 3, sesquioxide of chromium 19, ferric oxide 10, water 21 Okhansk in Siberia

664 ROTTISITE, $3\mathrm{NiSi} + 4\bar{\mathrm{H}}$

Amorphous and reniform Apple green to emerald green H = 2 to 2 5, G = 2 35 to 2 37 C c silica 43 7, nickel oxide 35 9 water 11 2 Rottis near Reichenbach in Saxony *Komarit* is similar.

665 URANOPHANE $3\mathrm{CaSi} + \bar{\mathrm{U}}_5\mathrm{Si}_3 + 18\bar{\mathrm{H}}$

Right prismatic $\infty\mathrm{P}$ 146° $\infty\breve{\mathrm{P}}\infty$, $\breve{\mathrm{P}}\infty$, with polar angle 90° Crystals honey yellow, when massive leek green H = 2 5 G = 2 6 to 2 8 C c silica 17 alumina 6 1, oxide of uranium 53 3, lime 5 1, water 15 1 Kupferberg in Silesia

666 URANOTILE, $\mathrm{CaSi} + \bar{\mathrm{U}}_3\mathrm{Si}_2 + 9\bar{\mathrm{H}}$

Right prismatic ∞P 164 In stellate groups Lemon yellow G = 3 96 C c silica 13 8, oxide of uranium 66 75, lime 5 27 water 12 67 Wolsendorf in Bavaria, Joachimsthal, Mitchel county in North Carolina

667 BISMUTOFERRITE, $\bar{\mathrm{Bi}},\ \mathrm{Si}_2, + 2\bar{\mathrm{Fe}},\mathrm{Si}$

Crypto crystalline, oblique prismatic Siskin- to olive green H = 3 5 G = 4 48 C c silica 24, oxide of bismuth 42 8, peroxide of iron 33 1 Schneeberg in Saxony *Hypochlorite* is a variety containing 13 of bismuth In a third variety, from Braunsdorf antimony replaces bismuth

SILICATES WITH TITANATES, NIOBATES, &c

668 SPHENE, $\mathrm{CaSi}_2 + \mathrm{CaTi}_2$

Oblique prismatic, C 85° 22′ $\infty\mathrm{P}$ (*l*) 133°2′, $\tfrac{1}{2}\mathrm{P}^{o}\infty$ (*x*) 55° 21, $\mathrm{P}^{o}\infty$ (*y*) 34° 21, $\infty\mathrm{P}^{c}\infty$ (*q*) 0P (*P* or *c*) 90°, $\infty\mathrm{P}^{c}3$ (*M*) 76° 7, $\mathrm{P}^{c}\infty$ (*r*) 113° 30, $\tfrac{2}{3}\mathrm{P}^{c}2$ (*n*) 136° 12, $4\mathrm{P}^{c}4$ (*s*) 67° 57 Crystals vary extremely in form, being generally apparently oblique tabular, from predominance of *n*, which are hemidomes in alternate position on opposite ends, also, but more rarely, prismatic, with dominance of *l* and *M* Twins frequent Twin face *c*, and formed by revolution either (*a*) on an axis normal to *c* or (*b*) on a vertical axis, the former very common and usually producing thin tables with a re entering angle along one side, and sometimes elongated Occasionally in double twins Sometimes granular or foliated Cl in some (*l*), in others (*r*) H = 5 to 5 5, G = 3 4 to 3 6 Semitransparent, adamantine or resinous.

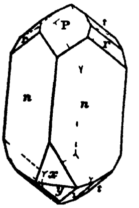


Fig 586.

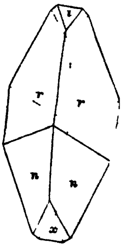


Fig 587.

Yellow, brown, and green B B fuses with micro salt in the red flame, gives reaction for titanic acid C c silica 30 6, titanic acid 40 8, lime 28 6 In Scotland, typical of syenites and primary limestones In minute hair brown crystals in the first, as at Lairg (Sutherland), Achavaiasdale (Caithness), and Criffel (Kirkcudbright) (figs 586 to 588) In the latter often in highly complex twins, yellow to brown, at Shinness (figs 193, 589), Urquhart, Dalnain, Torbane, &c, also with ilmenite and allanite in exfiltration veins of grey granite Dauphine, Mont Blanc, St Gotthard, Tyrol, Arendal, America *Greenovite*, flesh red from Glen Gairn in Aberdeenshire (like 194), and St Marcel in Piedmont, contains manganese at the latter locality

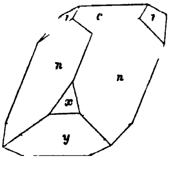


Fig 588

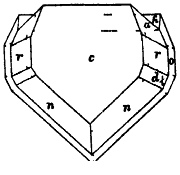


Fig 589

669 **Keilhalite** (*Yttrotitanite*), $5(CaY)(SiTi) + (\bar{A}l\bar{F}e)(SiTi)_3$

Oblique prismatic, C 58° ∞P 114 Cl −2P, 138° H =6 to 7 G =3 5 to 3 7 Blackish brown, streak greyish yellow B B with borax forms blood red glass in the red flame, other features like sphene C c 29 7 silica, 28 7 titanic acid, 21 1 lime, 10 8 yttria, 6 2 alumina, and 6 5 iron peroxide Near Arendal

670 **Schorlomite** (*Ferrotitanite*), $Ca_3Si + \bar{F}e_3Si_2 + CaTi_2$

Cubic, ∞O and 2O2, generally massive, fracture conchoidal H =7 to 7 5, G =3 8 Black streak grey black vitreous C c silica 26, titanic acid 23 3, peroxide of iron 20, lime 29 4 Arkansas, Kaiserstuhl, Ivaara in Finland Perhaps a titaniferous garnet

671 **Tschewkinite**

Massive, fracture flat conchoidal H =5 to 5 5, G =4 5 Opaque, vitreous, splendent Velvet black, streak dark brown B B intumesces greatly, becomes porous and often incandesces, in white heat fuses to black glass gelatinizes with h acid C c 21 silica, 20 titanic acid, 11 iron protoxide 45 peroxides of cerium metals with perhaps thoria, lime 4 Miask, Coromandel

672 **Mosandrite**

Oblique prismatic, C 71° 24½ ∞P (*t*) 88° 36′, ∞P°2 (*n*) ∞P°∞ (*a*) −P (*e*) 124° 1, P°∞ (*q*) ∞P°∞ *t a* 134° 18 *n a* 152° 52, *q a* 138° 2 Twin face the orthopinacoid Generally massive Fracture uneven H =4, G =2 93 to 3 Yellowish or reddish brown, streak pale green Vitreous to resinous lustre C c silica 29 9, titanic acid 9 9 oxide of cerium metals 26 5 lime 19, water 8 9 Brevig and Langesundfiord

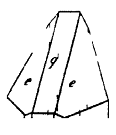


Fig 590 (sp 672)

673 **Eudialite** (*Eukolite*) $6RSi_2 + \dot{R}Zr$

Rhombohedral R 73° 10 R (*p*) 0R (a_1), ∞P2 (d_1), ¼R (a_2), also ∞R, ⅝R −½R −2R −⅛R R3 ⅔P2 (fig 591) Generally massive, granular Cl a_1 and a_2, fracture uneven H =5 to 5 5, G =2 84 to 2 95 Peachblossom red to brownish red, streak white Translucent, vitreous B B fuses easily to a light green opaque glass, gelatinizes in h acid C c silica 50, zirconia 16 9, protoxide of iron 7, lime 11, soda 12 Kangerdluarsuk in Greenland, Sedlovatoi Island in White Sea, Brevig (*Eukolite*), Magnet Cove in Arkansas

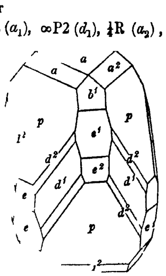


Fig 591 (sp 673)

674 **Catapleite** $2(\bar{N}a_2Ca)(SiZr)_9 + 9\dot{H}$

Hexagonal P 114° 43 0P, ∞P, P, also with 2P, and ½P In lamellar aggregates Cl prismatic and P, fracture uneven H =6, G =2 8 Yellowish brown to pale green, streak yellow, lustrous C c silica 46 7, zirconia 29 6, soda 10 8, water 9 Brevig

675 **Œrstedite**

Pyramidal P 84° 25′ P, ∞P, ∞P∞ Like zircon H =5 5, G =3 63 Lustre adamantine Reddish brown C c silica 19 7, titanate of zirconia 68 96, water 5 6 Arendal

676 **Wohlerite**, $9RSi + 3\dot{R}Zr + R\bar{N}b$

Oblique prismatic, C 70° 45 ∞P 90° 14, ∞P°2 127′ −P°∞ 43° 18′ 0P ∞P°∞ 109° 15, −P°∞ ∞P°∞ 136° 42, 0P ∞P 103° 31′ Crystals tabular and prismatic Cl clinodiagonal, fracture conchoidal H =5 to 6, G =3 4 Light yellow, honey yellow to brownish grey streak yellowish white C c silica 28, zirconia 19, niobic acid 13 9, lime 27 8, soda 8 3, protoxide of iron 3 B B fuses to yellowish glass Sol in h acid Langesundfiord, Brevig

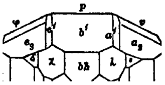


Fig 592

677 **Ardennite**

Right prismatic ∞P 131° 2′, P̄∞ 112° 24, P̄³⁄₂, ∞P̄³⁄₂, ∞P̆2, ∞P̄∞, ∞P̆∞ Crystals like ilvanite Cl brachydiagonal, and ∞P H =6 to 7, G =3 62 Yellow to yellow brown Dichroic, brittle C c silica 27 8, alumina 24, protoxide of manganese 26 7, lime 2 2, magnesia 4 3, vanadic acid 3 2, arsenic acid 6 3, water 5 Ottrez in the Ardennes (Luxemburg)

678 **Roscoelite**

Foliated masses, sometimes stellated H =1, G =2 3 to 2 9 Dark green to greenish blue Pearly lustre C c silica 47 7, vanadic acid 22 alumina 14 1, magnesia 2, potash 7 6, water 5 Eldorado in California

TITANATES WITH NIOBATES

679 **Titanomorphite**, CaTi

Oblique prismatic Like sphene ∞P, 0P ½P°∞, P°∞, ⅔P°2 C c titanic acid 74 3, lime 25 3 Lampersdorf in Silesia, Wuistritz

680 **Perovskite**, CaTi

Right prismatic In complicated twins, often distorted, pseudo cubic H =5 5 G =4 to 4 1 Lustre metallic adamantine Pale yellow, reddish brown to iron black, streak grey C c 58 8 titanic acid, 41 2 lime B B with micro salt in outer flame gives a bead greenish while hot, colourless on cooling, in inner flame grey green when hot, violet blue when cold Decomposed by boiling s acid Zlatoust Schelingen Zermatt, Malenco Valley near Sondrio, Pfitsch in Tyrol, Magnet Cove in Arkansas

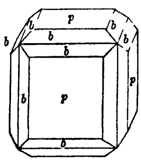


Fig 593

681 **Koppite**, $R_5\bar{N}b_2$

Cubic ∞O∞ G =4 45 to 4 56 Brown Transparent C c niobic acid 62 46, oxide of cerium 6 7, oxide of lanthanum 3 Schelingen on the Kaiserstuhl in Baden

682 **Annerodite**, $2R_2\bar{N}b + 5\dot{H}$

Right prismatic H =6 G 5 7 Metallic to greasy Black Streak black, brown, greenish grey Translucent in splinters, brittle C c 48 niobic acid with zirconia, thoria, ceria, yttria, and uranium oxide Annerod near Moss (Norway)

683 **Dysanalyte**, $6RTi + R\bar{N}b$

Cubic ∞O∞ Cl cubic G =4 13 Black C c titanic acid 41 5, niobic acid 23 2, cerium oxide 5 7 lime 19 8, protoxide of iron 5 8, soda 3 6 Vogtsburg on the Kaiserstuhl

684 **Pyrochlore**, $5R\bar{N}b + 4R(TiTh) + 4NaF$

Cubic (fig 594) Cl octahedral, brittle, fracture conchoidal. H =5, G =4 2 to 4 4 Resinous, opaque Red brown to black, ruby red and transparent rarely, streak pale brown C c niobic acid 53 2, titanic acid 10 5, thoria 7 6, cerium oxide 7, lime 14 2, soda 5, fluorine 3 1 Miask, Kaiserstuhl, Brevig, and Frederiksvarn *Microlite*, from Chesterfield in Massachusetts has tantalic acid 68 4, niobic acid 7 75 11 7 lime and 7 7 protoxide of manganese *Pyrrhite* from Mursinsk in the Urals, San Piero in Elba, and the Azores may be the same, at the last locality it is in orange red octahedra, and is a niobate of zirconia

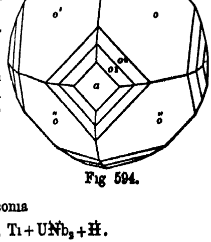


Fig 594.

685 **Blomstrandite**, $(Ca,Fe),Ti + U\bar{N}b_2 + \dot{H}$.

Massive. H =5 5 G =4 17 to 4 25 Vitreous, black. Streak brown Translucent in splinters C c niobic acid 49 8, titanic acid 10 7, uranium oxide 23 7, protoxide of iron 3 3, lime 3 5, water 7 9 Nohl (Sweden)

686 POLYCRASE, $4R\mathrm{Ti}+R\bar{\mathrm{N}}\mathrm{b}$

Right prismatic (fig 595) $\infty\breve{P}\infty$, ∞P (140°), P, $2\bar{P}\infty$ (56°) Fracture conchoidal H = 5 to 6, G = 5 1 Black, streak grey-brown. B B decrepitates violently, incandescing, but does not fuse Sol in s acid C c titanic acid 26 6, niobic acid 20 4, yttria 23 3, erbia 7 5, oxide of uranium 7 7, water 4 Hittero (Norway), Slettåkra in Jonkoping (Sweden)

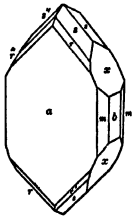


Fig 595

687 EUXENITE, $2R\mathrm{Ti}+R\bar{\mathrm{N}}\mathrm{b}+\dot{H}$

Right prismatic (fig 596) ∞P (m) 140°, $\infty\breve{P}\infty$ (b), $2\bar{P}\infty$ (d) 52°, P (p) 102° 58′ p b 103° 6 Fracture conchoidal Opaque, metallic to vitreous Black and brownish black, streak red brown B B infusible Not acted on by acids C c niobic acid 32, titanic acid 19 2, uranium oxide 19 5, yttria 18 2, cerium oxide 2 8, but variable Jolster, Tromo, Alvo, &c, in Norway, also Hittero and Cape Lindesnaes

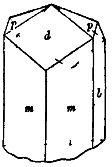


Fig 596

688 ÆSCHYNITE

Right prismatic ∞P (M) 128° 34′, $2\breve{P}\infty$ (y) 73° 16, P (o o) 137° 14, $\infty P3$ 69° 23, $\bar{P}\infty$, 0P Crystals long prismatic (fig 597) Cl traces, fracture imperfect conchoidal H = 5 to 5 5, G = 4 9 to 5 1 Opaque, submetallic or resinous Iron black or brown, streak yellowish brown B B swells and becomes yellow or brown, but is infusible Not sol in h acid, partially in s acid C c niobic and tantalic acids 28 8, titanic acid 22 6, thorium oxide 15 7, cerium protoxide 18 5, lanthanum oxide and didymium oxide 5 6 Miask, Hittero

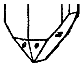


Fig 597 (sp 688)

689 POLYMIGNITE

Right prismatic P (p) polar 136° 28 and 116° 22′, ∞P 109° 46, $\infty\bar{P}\infty$, $\infty\breve{P}\infty$ (fig 598) Cl macro- and brachydiagonal, imperfect, fracture conchoidal H = 6 5, G = 4 7 to 4 8 Opaque, semimetallic Iron black, streak dark brown B B infusible Sol in h acid C c titanic acid 46 3, zirconia 14 1, yttria 11 5, lime 4 1, iron peroxide 12 2, cerium oxide 5 Frederiksvarn

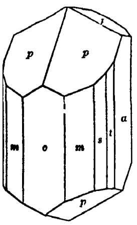


Fig 598 (sp 689)

690 MENGITE, $(\bar{\mathrm{F}}\mathrm{e}, \bar{\mathrm{Z}}\mathrm{r})\,\mathrm{Ti}$

Right prismatic P (e) polar angle 151° 27′ and 101° 10, ∞P 136° 20, $\infty\breve{P}3$, $\infty\bar{P}\infty$ (fig 599) Fracture uneven. H = 5 to 5 5, G = 5 48 Opaque, semimetallic Iron-black, streak chestnut brown B B infusible, but becomes magnetic Sol in s acid Miask, Groix island in Morbihan

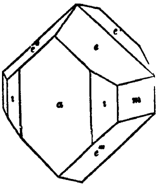


Fig 599 (sp 690)

691 TANTALITE, $\mathrm{Fe}\,(\bar{\mathrm{T}}\mathrm{a}, \bar{\mathrm{N}}\mathrm{b})$

Right prismatic P (p) with polar edges 126° and 112° 30′, middle 91° 42′ $\infty\breve{P}\frac{2}{3}$ (r) 122° 53 $\infty\bar{P}\infty$ (s), $\infty\breve{P}\infty$ (t), $\breve{P}\infty$ (m) 113° 48, $3\breve{P}\infty$ (q) 54° 10′, $\frac{1}{3}\breve{P}\infty$ (n) 167° 36′, $\frac{3}{2}\breve{P}\frac{3}{2}$ (v), $2\breve{P}2$ (o) Fracture conchoidal or uneven H = 6 to 6 5, G = 6 1 to 8 Opaque, semimetallic, adamantine, or resinous Iron black, streak cinnamon- or coffee-brown B B infusible, scarcely affected by acids C c 76 to 50 tantalic acid, 7 5 to 29 niobic acid, 9 to 16 iron protoxide, and 1 to 6 manganese protoxide, some with 1 to 10 tin oxide (*Cassiterotantalite*), also in union with iron (manganese) protoxide Kimito and Tammela in Finland, Broddbo and Finbo near Falun, and Chanteloube near Limoges, always in granite

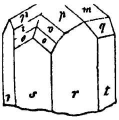


Fig 600

692 TAPIOLITE, $4\mathrm{Fe}\bar{\mathrm{T}}\mathrm{a}+\mathrm{Fe}\bar{\mathrm{N}}\mathrm{b}$.

Pyramidal. P middle angle 84° 52′, summit 123° 1′ H. = 6, G = 7 2 to 7 5 Black Lustrous C c tantalic acid 78·9, niobic acid 11 2, protoxide of iron 15 Tammela in Finland.

693 COLUMBITE, $m\mathrm{Fe}\bar{\mathrm{N}}\mathrm{b}+n\mathrm{Fe}\bar{\mathrm{T}}\mathrm{a}$

Right prismatic P (u) polar angles 104° 10′ and 151°, middle angle 83° 8′, 0P (c), $\infty\breve{P}\infty$ (b), $\infty\bar{P}\infty$ (a), ∞P (g) 135° 40′, $\infty\breve{P}\infty$ (m) 101° 26′, 2P (s), $3\breve{P}3$ (o), $3\breve{P}\frac{3}{2}$ (π), $\frac{1}{2}\breve{P}\infty$ (l) 161°, $\breve{P}\infty$ (k) 143°, $2\breve{P}\infty$ (h) 112° 26′, $\bar{P}\infty$ (i) 101° 12′, $2\bar{P}\infty$ (e) 62° 40′ Hemitropes, face e, vertical axes forming an angle of 62° 40′, also on faces 2P2 (n), and rarely b Also granular and foliated Cl. brachydiagonal, perfect, also macrodiagonal H = 6, G = 5 4 to 6 4 Metallic, adamantine Iron black to brownish, streak black or reddish brown B B infusible not affected by acids C c isomorphic mixtures of niobic and tantalic acids with protoxide of iron (or manganese) Pure columbite would give 78 8 niobic acid, pure tantalite 86 tantalic acid The niobic acid generally prevails, and the crystals are better formed the more this is the case Rabenstein, Bodenmais, Chanteloube Finland, Ilmen Hills, Evigtok in Greenland, Haddam and Middletown in Connecticut, Acworth in New Hampshire, Pike s Peak in Colorado

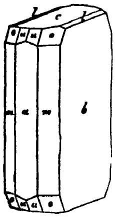


Fig 601

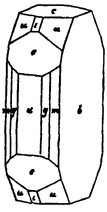


Fig 602

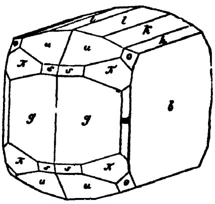


Fig 603

694 YTTROTANTALITE, (Y, Ca, Fe U) $(\bar{\mathrm{T}}\mathrm{a}, \mathrm{W}, \bar{\mathrm{N}}\mathrm{b})$

In two varieties (a) *Black* Right prismatic in short prismatic or tabular crystals $\infty\breve{P}\infty$, ∞P (m) 121° 48 0P $2\breve{P}\infty$ 103° 26′, $\breve{P}\infty$ 0P 131° 26, i i 149° 42′ (fig 604), also in grains and lamellæ Cl brachydiagonal, indistinct, fracture conchoidal or uneven Opaque, or in thin splinters translucent Velvet black, semimetallic lustre, and greenish grey streak H = 5 5, G = 5 4 to 5 7 (b) *Yellow* Amorphous, yellowish brown, or yellow, often striped or spotted, resinous or vitreous, streak white G = 5 46 to 5 88 Both varieties B B infusible, but become brown or yellow Not affected by acids C c 57 to 60 tantalic acid, 1 to 8 tungstic acid, 0 to 20 niobic acid, 20 to 38 yttria, 0 5 to 6 lime, 0 5 to 6 uranium peroxide, and 0 5 to 3 5 iron peroxide Ytterby, and near Falun

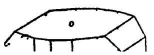


Fig 604

695 FERGUSONITE, (Y, Er, Ce)$_3$$(\bar{\mathrm{N}}\mathrm{b}\ \bar{\mathrm{T}}\mathrm{a})$

Pyramidal and hemihedric, P (s) 128° 28′ Usual form ($\frac{1}{2}$) $3P\frac{3}{2}$ (z) P, $\frac{1}{2}\infty P\frac{3}{2}$ (q), 0P (c) (fig 605) s s 100° 54, s c 115° 16′, z r 169° 17 Cl traces along P, fracture imperfect conchoidal, brittle H = 5 5 to 6, G = 5 6 to 5 9 Translucent in thin splinters, semimetallic Brownish black, streak pale brown B B infusible C c chiefly niobic acid and yttria, with erbia, also a little cerium protoxide, tin oxide, uranium oxide, and iron protoxide Cape Farewell in Greenland, Ytterby, Riesengebirge, Rockport in Massachusetts *Tyrite*, from Helle near Arendal, is similar

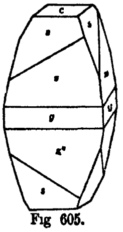


Fig 605.

696 HJELMITE

Massive, with granular fracture and traces of crystals H = 5, G = 5 82 Velvet black, streak greyish black Lustre metallic C c tantalic acid 62 4, tin 6 6, uranium 4 9, protoxide of iron 8 1, yttria 5 2 B B infusible In closed tube decrepitates and yields water Karartvet near Falun

697 SAMARSKITE (*Uranotantalite*), $(\dot{R}_3, \bar{R}, \ddot{R}\frac{3}{2})_5(\bar{\mathrm{N}}\mathrm{b}\bar{\mathrm{T}}\mathrm{a})_3$

Right prismatic ∞P 122° 46′, $\infty\breve{P}2$ 95°, $\bar{P}\infty$ 93°, P, $\infty\bar{P}\infty$, $\infty\breve{P}\infty$, $3\breve{P}\frac{3}{2}$ also in grains Fracture conchoidal, brittle H = 5 56, G = 5 6 to 5 76 Opaque, strong semimetallic Velvet-black, streak dark reddish brown B B fuses on the edges to a black glass. In the closed tube decrepitates, yields water, incandesces, and becomes brown Sol in h acid to a greenish fluid.

C c 37 2 niobic acid 18 6 tantalic acid, 12 iron protoxide 14 to 20 uranium oxide 6 thorium oxide 4 zirconia, and 16 yttria with lime and magnesia Miask, Mitchell county in North Carolina The *Yttroilmenite* of Hermann

698 NOHLITE R_3Nb

Massive H = 4 5 to 5, G = 5 04 Black brown Splintery Brittle Opaque vitreous Niobic acid 50 4, uranium oxide 14 4 zirconia 3 ferrous oxide 8 yttria 14 4, lime 4 7, water 4 6 Nohl near Kongelf (Sweden)

699 HATCHETTOLITE

Cubic O ∞O∞ Yellowish brown Resinous lustre Fracture conchoidal H = 5, G = 4 8 to 4 9 C c niobic acid 34 3 tantalic acid 29 8, uranium oxide 15 5, lime 8 9 water 4 5 North Carolina

ANTIMONIALS

700 ROMEITE, Ca_3SbSb

Pyramidal P 110° 50 Scratches glass G = 4 7 or hyacinth red B B fuses to a blackish slag Sol in acids C c 41 3 *antimonic acid, 37 3 antimony oxide*, and 21 4 lime, but with 2 to 3 manganese and iron protoxide St Marcel in Piedmont *Schneebergite* from Tyrol, may be an impure variety

701 BLEINIERITE, $Pb(Sb, Sb)+H$

Reniform and massive H = 4, G = 3 9 to 4 8 Translucent, resinous to earthy Colourless, yellow, brown, and grey B B reduced on charcoal C c oxide of lead 41 to 62, antimonious acid 32 to 47 water 6 to 12 Lostwithiel, Horhausen, Nertchinsk

702 NADORITE $PbSb+PbCl$

Right prismatic ∞P 132° 51 Crystals tabular Cl macro diagonal H = 3, G = 7 Yellowish or greyish brown Resinous to adamantine translucent C c lead 52 2, antimony 30 8, oxygen 8, chlorine 9 Constantine (Algeria)

703 RIVOTITE

Massive Yellowish to greyish green Opaque, fracture uneven, brittle H = 3 5 to 4, G = 3 6 C c oxide of copper 39 5, oxide of silver 1 2, antimonic acid 42, carbonic acid 21 Sierra del Cadi in the province of Lerida *Thrombolite* from Rezbanya, Hungary may be a hydrated variety

704 MELLITE, $Al(C_1O_9)+18H$

Pyramidal P 93° 5 0P P∞ and ∞P∞ Cl P, fracture conchoidal brittle H = 2 to 2 5 G = 1 5 to 1 6 Transparent doubly refractive, vitreous Honey yellow or reddish, streak white In closed tube yields water B B chars without odour Burns white and acts like alumina Sol in n acid or potash C c alumina 14 4 mellic acid 40 3 water 45 3 In lignite at Artern in Thuringia and Luschitz in Bohemia, Walchow Moravia (cretaceous in coal at Malovka in Tula

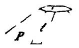


Fig 606

705 OXALITE, $2Fe\Theta_3+3H$

Capillary crystals, also botryoidal or compact fracture uneven, sectile H = 2 G = 2 2 Opaque, resinous to dull Straw yellow B B turns black then red Sol to yellow solution in acids C c 42 1 iron protoxide, 42 1 oxalic acid, 15 8 water In lignite at Kolosoruk near Bilin, Duisburg, and Gross Almerode in Hesse

706 WHEWELLITE, $Ca\Theta+H$

Oblique prismatic, C 72° 41 ∞P 100° 36 Cl basal, perfect, brittle H = 2 5 to 2 8, G = 1 838 Transparent to opaque, vitreous Colourless C c 49 31 oxalic acid, 38 36 lime, 12 33 water Hungary

THE MINERAL RESINS

Many of these are only vegetable resins slightly altered Naphtha is fluid, the others solid, with H = 1 to 2 or 2 5 Most are amorphous, a few crystalline and monoclinic G = 0 6 to 1 6 Mostly resinous, colourless, or coloured brown, yellow, or red, with paler streak Sol in acids alcohol, ether, and oils Melt readily, and burn with flame and smoke

707 NAPHTHA, PETROLEUM CH_2

Liquid Colourless, yellow, or brown Transparent or translucent G = 0 7 to 0 9 Volatilizes in the atmosphere with an aromatic bituminous odour C c 84 to 88 carbon, and 12 to 16 hydrogen Varieties are—

Naphtha—Very fluid, transparent, and light yellow Tegern Lake in Bavaria, Amiano near Parma, Salies in the Pyrenees, Rangoon, Baku on the Caspian Sea, China, Persia, and North America. Used for burning, and in preparing varnishes

Petroleum—Darker yellow or blackish brown, less fluid or volatile Ormskirk in Lancashire, Coalbrookdale Pitchford, and Madeley in Shropshire, St Catherine's Well, south of Edinburgh; Mainland of Orkney, and many other parts of Europe

708 ELATERITE (*Elastic Bitumen, Mineral Caoutchouc*), CH_2

Compact, reniform or fungoid, elastic and flexible like caoutchouc, very soft G = 0 8 to 1 23 Resinous Blackish, reddish, or yellowish brown Strong bituminous odour C c 84 to 86 carbon, 12 to 14 hydrogen, and a little oxygen Derbyshire Montrelais near Nantes, and Woodbury in Connecticut

709 ASPHALTUM, BITUMEN

Compact and disseminated, fracture conchoidal, sometimes vesicular, sectile H = 2, G = 1 1 to 1 2 Opaque, resinous, and pitch black, strong bituminous odour, especially when rubbed Takes fire easily, and burns with a bright flame and thick smoke Sol in ether, except a small remainder, which is dissolved in oil of turpentine C c 76 to 88 carbon, 2 to 10 oxygen, 6 to 10 hydrogen, and 1 to 3 nitrogen Limmer near Hanover, Seyssel on the Rhone, Val Travers in Neufchatel, Lobsann in Alsace, in the Harz, Dead Sea, Persia, and Trinidad, Cornwall, Haughmond Hill (Shropshire), East and West Lothians, Elie and Burntisland (Fife)

710 ALBERTITE

Massive Velvet black Adamantine lustre, brittle C c carbon 86, hydrogen 9, nitrogen 2 9, oxygen 2 Hoy, Orkney, Strathpeffer Ross, Hillsborough, New Brunswick

711 PIAUZITE

Massive, imperfect conchoidal, sectile H = 1 5, G = 1 22 Dimly translucent on very thin edges, resinous Blackish brown, streak yellowish brown Fuses at 600° Fahr, and burns with an aromatic odour, lively flame, and dense smoke Sol in ether and caustic potash Piauze near Rudolfswerth in Carniola

712 IXOLYTE

Massive, conchoidal fracture H = 7, G = 1 008 Resinous Hyacinth red, streak ochre yellow Rubbed between the fingers it emits an aromatic odour, becomes soft at 119°, but is still viscid at 212° Oberhart near Gloggnitz in Austria

713 AMBER (*Succinite*), $C_{10}H_8O$

Round irregular lumps grains or drops Fracture perfect conchoidal, slightly brittle H = 2 to 2 5, G = 1 to 1 1 Transparent to translucent or almost opaque, resinous Honey yellow, hyacinth red, brown, yellowish white, also streaked or spotted When rubbed emits an agreeable odour, and becomes negatively electric It melts at 550°, emitting water, an empyreumatic oil, and succinic acid, it burns with a bright flame and pleasant odour, leaving a carbonaceous remainder, only a small part is soluble in alcohol C c 79 carbon, 10 5 hydrogen, and 10 5 oxygen Derived chiefly from an extinct coniferous tree (*Pinites succinifer*) and found in the Tertiary and diluvial formations of many countries, especially northern Germany and shores of the Baltic, Sicily, Spain, and northern Italy rarely in Britain (on the shores of Fife, Norfolk, Suffolk, and Essex, and at Kensington, near London) Used for ornamental purposes, and for preparing succinic acid and varnishes *Krantzite*, from Nienburg is essentially the same

714 RETINITE (*Retinasphalt*)

Roundish or irregular lumps, fracture uneven or conchoidal, very easily frangible H = 1 5 to 2, G = 1 05 to 1 15 Translucent or opaque, resinous or glistening Yellow or brown Melts at a low heat, and burns with an aromatic or bituminous odour C c in general carbon, hydrogen, and oxygen, in very uncertain amount Bovey, Halle, Cape Sable, and Osnabruck *Pyroretinite* from Aussig in Bohemia is similar

715 WALCHOWITE, $C_{12}H_9O$

Rounded pieces, with a conchoidal fracture H = 1 5 to 2, G = 1 035 to 1 069 Translucent, resinous Yellow with brown stripes, and a yellowish white streak It fuses at 482°, and burns readily Soluble partially (7 5 per cent) in ether, in s acid forms a dark brown solution C c 80 4 carbon, 10 7 hydrogen, and 8 9 oxygen Walchow in Moravia

716 COPALINE (*Fossil Copal, Highgate Resin*), $C_{40}H_{64}O$

Irregular fragments H = 1 5, G = 1 046 Translucent, resinous, burns with light yellow flame and much smoke, alcohol dissolves little of it, becomes black in sulphuric acid C c 85 54 carbon, 11 63 hydrogen, 2 76 oxygen Highgate near London A similar resin from Settling Stones mine in Northumberland, found in flat drops or crusts on calc spar, is infusible at 500° Fahr, G = 1 16 to 54, it contains 85 13 carbon, 10 85 hydrogen, and 3 26 ashes

717 BERENGELITE, $C_{40}H_{62}O_8$

Amorphous, conchoidal fracture Dark brown, inclining to green, yellow streak Resinous, unpleasant odour, and bitter taste Fuses below 212°, and continues soft afterwards at ordinary temperatures, easily soluble in alcohol C c 72 40 carbon, 9 28 hydrogen, 18 31 oxygen San Juan de Berengela in Peru.

718 GUAYAQUILLITE, $C_{20}H_{26}O_3$

Amorphous, yielding easily to the knife, and very friable. G.

=1 092 Pale yellow Slightly resinous Fluid at 212°, viscid when cold, slightly soluble in water, and largely in alcohol, forming a yellow fluid with a bitter taste C c 77 01 carbon, 8 18 hydrogen, and 14 80 oxygen Guayaquil in South America

Bogbutter, from the Irish peat mosses, is similar, it melts at 124°, is easily soluble in alcohol, and contains 73 70 carbon, 12 50 hydrogen, and 13 72 oxygen

719 HARTINE, $C_{20}H_{20}+\bar{H}$

Round masses or thin layers Brittle, but easily cut with a knife G =1 6 Resinous Reddish brown by reflected and deep red by transmitted light, streak light brown Becomes black on exposure C c 86 43 carbon, 8 01 hydrogen, 5 56 oxygen In the main coal seam at Middleton near Leeds, and at Newcastle

720 OZOCERITE (*Native Paraffin*), CH

Amorphous sometimes fibrous Very soft pliable, and easily fashioned with the fingers G =0 94 to 0 97 Glimmering or glistening, semitranslucent Yellowish brown or hyacinth red by transmitted, dark leek green by reflected light Strong paraffin or aromatic odour, fuses easily to a clear oily fluid, at higher temperature burns with a clear flame, seldom leaving any ashes readily soluble in oil of turpentine, with great difficulty in alcohol or ether C c 85 7 carbon, and 14 3 hydrogen Binny (Linlithgow), and Edinburgh, Slanik and Zietriska in Moldavia, near Garming in Austria, and Baku, also at Urpeth coal mine near Newcastle on Tyne *Pyropissite* may be a variety

721 HATCHETTINE (*Mineral Tallow*)

Flaky, like spermaceti or subgranular, like beeswax soft and flexible G =0 6 Translucent weak pearly Yellowish white wax yellow, or greenish yellow Greasy inodorous readily soluble in ether C c 85 91 carbon, 14 62 hydrogen, or similar to ozocerite Loch Fyne (fusible at 115°), Merthyr Tydvil, Schaumburg

722 FICHTELITE, C_4H_3.

Crystalline (oblique prismatic) lamellæ, which swim in water but sink in alcohol White and pearly Fuse at 114°, but again become crystalline on cooling Very easily soluble in ether, and precipitated by alcohol C c 88 9 carbon and 11 1 hydrogen In pine wood in a peat moss near Redwitz in Bavaria

723 HARTITE, C_6H_5.

Anorthic, but mostly like spermaceti or white wax, and lamellar Sectile, but not flexible H =1 G =1 046 Translucent dull resinous White Melts at 165° and burns with much smoke Very soluble in ether, much less so in alcohol C c 87 8 carbon and 12 2 hydrogen Oberhart in Austria

724 KONLITE C H

Crystalline folia and grains Soft G =0 88 Translucent resinous White without smell Fuses at 120° to 137° Sol in n acid precipitated by water in a white crystalline mass C c 92 3 carbon, 7 7 hydrogen Uznach near St Gall, Redwitz

725 SCHEERERITE CH₂

Oblique prismatic tabular or acicular Soft and rather brittle G =1 to 1 2 Translucent resinous or adamantine White inclining to yellow or green Feels greasy, has no taste and when cold no smell but when heated a weak aromatic odour Insoluble in water, readily sol in alcohol ether and n and s acids C c 75 carbon, 25 hydrogen Uznach *Branchite* white, translucent, fusing at 167°, is similar, Montevaso in Tuscany

726 IDRIALITE, C_3H_2

Massive fracture uneven or slaty sectile H =1 to 1 G =1 4 to 1 6 (1 7 to 3 2) Opaque resinous Greyish or brownish black, streak blackish brown inclining to red Feels greasy Burns with a thick smoky flame, giving out sulphurous acid, and leaving some reddish brown ashes C c 77 idrialine (=94 7 carbon and 5 3 hydrogen) and 18 cinnabar, with a little silica, alumina, pyrite, and lime The idrialine may be extracted by warm olive oil or oil of turpentine as a pearly shining mass, difficultly fusible Idria

727 TORBANITE

Massive, fracture subconchoidal Yellow, brown grey, and light brown H =1 5 to 2, G =1 28 C c 60 to 65 carbon, 9 hydrogen, 4 to 5 oxygen, 10 to 20 silicate of alumina. When distilled below redness yields a burning fluid holding paraffin in solution, above redness a large quantity of highly illuminating gas Shown by the microscope to consist of granules of a yellow bituminoid wax, with interstitial shaly matter Torbanehill in Scotland, Pilsen in Bohemia, Kurakina and Murayevna in Russia

728 DOPPLERITE

Jelly like elastic masses Brownish black, streak brown Greasy lustre H =0 5, G =1 1 After drying H =2 5, G =1 5 Insoluble in alcohol and ether An acid substance related to humic acid From peat beds, Aussee (Styria) and Switzerland

THE COALS

729 ANTHRACITE (*Glance Coal*)

Massive and disseminated, rarely columnar Fracture conchoidal, brittle H =2 to 2 5, G =1 4 to 1 7 Opaque brilliant metallic Iron black, streak unaltered Perfect conductor of electricity Burns difficultly with a very weak or no flame, and does not cake, in the closed tube yields a little moisture, but no empyreumatic oil, detonates with nitre C c carbon above 90 per cent, with 1 to 3 oxygen, 1 to 4 hydrogen, and 0 to 3 nitrogen, and ashes chiefly of silica, alumina, lime, and peroxide of iron Common in some parts of all coal fields, and especially in the United States, as in Rhode Island, Massachusetts, and above all in Pennsylvania Used chiefly for manufacturing metals

730 COMMON COAL (*Black Coal, Stone or Mineral Coal, Bituminous Coal*)

Compact, slaty, or confusedly fibrous, often dividing into rhomboidal columnar, or cubical fragments Fracture conchoidal, uneven, or fibrous rather brittle or sectile H =2 to 2 5, G =1 2 to 1 5 Vitreous resinous or silky in the fibrous variety Blackish brown, pitch black or velvet black Burns easily, emitting flame and smoke with a bituminous odour heated in the closed tube yields much oil C c 74 to 90 carbon, with 0 6 to 8 or 15 oxygen, 3 to 6 hydrogen, 0 to 1 to 2 nitrogen, 0 1 to 3 sulphur, and 1 to 11 earthy matters or ash in 100 parts

Slate Coal or *Splint* has a thick slaty structure, and an uneven fracture *Cherry Coal* is the name applied to the brittle highly lustrous variety common in the English coal fields *Caking Coal* is a more bituminous variety which undergoes semifusion when ignited, caking or agglutinating during combustion *Cannel Coal* has a resinous, glimmering lustre, and a flat conchoidal fracture breaks into irregular cubical fragments, but is more solid and takes a higher polish than other varieties This burns with a bright flame, and yields much gas Abundant in many lands, as in England, Scotland, and Ireland, in Belgium and France in Germany and southern Russia British America and the United States possess immense fields, especially in the valley of the Mississippi Also found in China, Japan Hindustan, Australia, Borneo, and several of the Indian islands

731 LIGNITE (*Jet, Brown Coal*)

Distinctly vegetable in origin,—the external form, and very often the internal woody structure, being preserved The texture is compact woody, or earthy Fracture conchoidal woody or uneven, soft and often friable G =0 5 to 1 5 Lustre sometimes resinous, mostly glimmering or dull Brown black, or rarely grey Burns easily with an unpleasant odour colours solution of potash deep brown C c 47 to 73 carbon, 2 5 to 7 5 hydrogen 8 to 33 oxygen (with nitrogen), and 1 to 15 ashes *Jet* is pitch black with conchoidal fracture and resinous lustre Brown coal occurs at Bovey Tracy in Devonshire also in Germany Hungary France, Italy and Greece The *Surturbrand* of Iceland seems a variety Used as fuel, but much inferior to common coal The Oolitic coals of Yorkshire, Antrim, Brora, Mull, and Skye are intermediate varieties

INDEX OF MINERAL SPECIES

Abriachanite 581
Acanthite 170
Acmite, 570
Actinolite 578
Adamite 410
Adinole 590
Adularia 589
Ægerine 571
Æschynite, 688
Agalmatolite, 647
Aikinite 231
Alabandine 180
Alabaster 319
Alalite 567
Albertite 710
Albite 590
Alexandrite 94
Algodonite 192
Allanite 474
Allemontite 7
Allochroite 493
Allomorphite 313
Allopalladium 30
Allophane 639
Almandine, 493
Alstonite 283
Altaite 163
Alum 341
Aluminite 329
Alunite 343
Alunogene 328
Amalgam 24
Amazon stone 589
Amber 713
Amblygonite 450
Amblystegite, 565
Amethyst 81 135
Amianthus 567 578
Amphibole 578
Amphodelite 591
Analcime 605
Anatase 96
Anauxite 641
Andalusite 460
Andesine, 594
Anglesite 316
Anhydrite 317
Ankerite 2 4
Annabergite 388
Annerodite 687
Annivite, 233
Anomite, 515
Anorthite 591
Anthophyllite 577
Anthracite, 729
Anthraconite 272
Antigorite 551
Antimonial nickel 184
Antimony 6
Apatelite 331
Apatite 443
Aphrite 272
Aphrodite 543
Apophyllite, 603
Aquamarine 586
Aragonite 281
Arcanite 308
Ardennite 677
Arfvedsonite 579
Argentite 169
Arkansite 97
Arksutite 41
Arquerite 23
Arsenic 6
Arseniosiderite, 429
Arsenolite 123
Asbestos 578
Asphaltum 709
Astrakanite 337
Astrophyllite 530
Atacamite 63
Atopite 376
Augite 567
Aurichalcite, 297
Avaite 28
Avanturine 135
Axinite 414
Azurite, 294
Babingtonite 575
Baikalite 567
Barsovite 596
Baryta mica 521
Baryte 313
Baryto calcite 287
Baryto celestine 314
Bastite 564
Bastnaesite 37
Beaumontite 614
Beauxite, 112
Beegerite 160
Beraunite 400
Berengelite 717
Bergholz 660
Berthierine 562
Berthierite 218
Beryl 586
Berzelinite 106
Berzelite 3 0
Beudantite 456
Bieberite 327
Binnite, 221
Biotite, 512
Bismite 126
Bismuth 8
Bismuthine 209
Bismuthite, 302
Bismutoferrite, 667.

Bismuto-sphærite 288
Bitter spar 273
Bitumen 708 709
Bleiniere 701
Blende 177
Blodite 337
Blomstrandite 685
Bloodstone 135
Bodenite 474
Bogbutter 718
Bogoslovskite 492
Bole 655
Bolivite 256
Bolognese stone 313
Boltonite 476
Bonsdorfite 585
Boracite 262
Borax 266
Bornite 190
Borocalcite 267
Botryogene 347
Botryolite 470
Boulangerite 227
Bournonite 230
Branchite 726
Brandisite 524
Braunite 100
Bravaisite 673
Breislakite 567
Breithauptite 184
Breunnerite 2 6
Brewsterite 615
Brochantite 334
Bromite 56
Brongniartine 311
Bronzite 564
Brookite 97
Brown coal 731
Brucite 114
Brushite 377
Bunsenite 76
Bustamite 574
Byrichrite 155
Byssolite 578
Cacholong 137
Cacoxene 402
Cairngorm 135
Calaite 404
Calamine 280
Calcite calc spar 272
Caledonite 350
Calomel 49
Cancrinite 506
Caporcianite 612
Carbuncle 493
Carnallite 62
Carnat 631
Carnelian 135
Carpholite 656
Carphosiderite 332
Cassiterite 98
Cassiterotantalite 691
Castor 573
Catapleite 674
Cat's eye 135
Cawk 313
Celadonite 560
Celestine 315
Centrolite 488
Cerargyrite 54
Cerine 474
Cerite 484
Cerussite 286
Cervantite 130
Chabasite 608
Chalcanthite 333
Chalcedony 135
Chalcolite 439
Chalcomenite 257
Chalcophanite 1 2
Chalcophyllite 435
Chalcopyrite 189
Chalcosiderite 430
Chalcotrichite 73
Chalk 272
Chalybite 277
Chamoisite 562
Chert 135
Chiastolite 460
Childrenite 432
Chilenite, 197
Chiolite 42
Chiviatite 248
Chladnite 563
Chloantite 146
Chlorite 31
Chloritoid 526
Chlorocalcite 53
Chloropal 657
Chlorophæite 556
Chlorophyllite 585
Chlorospinel 93
Chodneffite 43
Chondrarsenite 395
Chondrodite 482
Chonicrite 535
Chrome ochre 637
Chromite 89
Chrysoberyl 94
Chrysocolla 491
Chrysolite 4 8
Chrysoprase 135
Chrysotile 549
Cimolite 638
Cinnabar 198
Cinnamon stone 493
Cipollino 272
Clarite 246
Clausthalite 161
Clay ironstone 277
Clays 629
Clinochlore 533
Clinoclase 424
Clintonite 524
Coals 729 731
Cobaltite 143
Cobaltspath 279
Cobalt vitriol 327
Coccinite 58
Coccolite 567
Cœruleolactin 405
Colophonite 493
Coloradoite 202
Columbite 693
Condurrite 192
Connellite 2
Copaline 716
Copiapite 331
Copper 18
Copperas 324
Copper blende 238
Coquimbite 330
Cordierite 85
Cornwallite 418
Corundophyllite 533
Corundum 81
Cotton stone 623
Cotunnite 60
Covelline 188
Crednerite 102
Crichtonite 83
Crocalite 692
Crocoisite 355
Cronstedtite 539
Crookesite 16
Cryolite 40
Cryophyllite 517
Cryptolite 367
Cuban 191
Cube ore 403
Cuprite 73
Cuproplumbite 159
Cyanite 461
Cymophane 94
Cyprine 4 5
Danalite 497
Danburite 49
Dawsonite 1 2
Datholite 467
Davidsonite 586
Davyne 06
Dechenite 3 3
Delafossite 3
Delessite 538
Demidowite 492
Dermatine 5 5
Descloizite 414
Diadochite 4 4
Diallage 68
Dialogite 8
Diamond 13
Diaspore 107
Dichroite 585
Dickinsonite 392
Dietrichite 341
Dihydrite 419
Dimorphite 207
Diopside 567
Dioptase 490
Diphanite 522
Dipyre 502
Discrasite, 176
Disthene 461
Dolomite 273
Domeykite 192
Dopplerite 728
Dufrenite 399
Dufrenoysite 223
Durangite 451
Dysanalyte, 683
Dysluite 91
Ecdemite 458
Edingtonite 620
Ehlite 421
Eisennickelkies 182
Elæolite 506
Elaterite 708
Electrum 25
Eleonorite 401
Eliasite 113
Embolite 55
Embrethite 227
Emerald 81 586
Emerald nickel 298
Emery 81
Emmonite 284
Emplectite 216
Enargite 24
Enstatite 563
Eosite 359
Eosphorite 433
Epiboulangerite 2 0
Epichlorite 533
Epidote 4 5
Epigenite 249
Epistilbite 613
Epsomite 321
Erinite 418
Erythrosiderite 65
Erythrite 386
Esmarkite 585
Euchroite 417
Euclase 468
Eucrasite 643
Eudialyte 6 3
Eudnophite 605
Eukairite 168
Eukolite 6 3
Eulytine 498
Euphyllite 523
Euxenite 687
Evansite 406
Evigtokite 4
Fahlerz 237
Fahlunite 585
Fairfieldite 394
Famatinite 24
Fargite 623
Faroelite 626
Fassaite 567
Faujasite 607
Fayalite 4 7
Felinite 655
Felsobanyite 329
Felspars 589 597
Ferberite 364
Fergusonite 695
Ferrotitanite 670
Fetbol 655
Fibroferrite 331
Fichtelite 722
Fillowite 390
Fiorite 137
Fire blende 252
Fischerite 40
Flint 135
Fluellite 39
Fluocerine 36
Fluocerite 3
Fluorite fluor-spar 33
Forchhammerite 507
Foresite 621
Forsterite 476
Fowlerite 74
Franklinite 88
Frenzelite 210
Friedelite 628
Frieseite 186
Frieslebenite 224
Fuchite 519
Fuller's earth 632
Gadolinite 471
Gahnite 91
Galactite 623
Galena, 158
Galmei 485
Garnet 493
Gaylussite 292
Gearksutite 46
Gehlenite 504
Gelbeisenerz 345
Geocronite 241
Gersdorffite 147
Gibbsite 116
Gieseckite 585 650
Gigantolite 585
Gilbertite 519
Giobertite 276
Girasol 137
Gismondine 624
Glagerite 633
Glaserite 308
Glauberite 311
Glaucodote 144
Glauconite 559
Glaucophane 582
Gmelinite 609
Gold 25
Goslarite 322
Gothite 108
Grammatite 578
Graphic granite 589
Graphite 14
Greenockite 179
Greenovite 668
Grunauite 154
Grunerite 584
Guanajuatite 201
Guayaquillite 718
Guejarite 211
Gummite 120
Gymnite 547
Gypsum 319
Gyrolite 604
Hæmatite 82
Haidingerite 379
Hair salt 328
Halite 51
Halloysite 632
Hamartite 38
Harmotome 617
Hartine 719
Hartite 723
Hatchettine 721
Hatchettolite 699
Hauerite 150
Haughtonite 513
Hausmannite 99
Hauyne 510
Haydenite 608
Haytorite 467
Heliotrope 135
Helvine 496
Hepatite 313
Hercynite 92
Herderite 452
Hermannite 583
Herrengrundite 348
Herschelite 611
Hessite 174
Heterozite 391
Heulandite 614
Hisingerite 659
Hislopite 272
Hjelmite 696
Homilite 469
Hopeite 409
Horbachite 156
Hornblende 578
Hornesite 383
Hornstone 135 589
Hubnerite 365
Hudsonite 567
Humboldtilite 503
Humite 482
Hureaulite 391
Huronite 585
Hyacinth 138
Hyalite 137
Hyalophane, 595
Hyalosiderite 478
Hydrargillite, 116
Hydroboracite 270
Hydromagnesite 293
Hydrophane 137
Hydrophite 552
Hydrotalcite 118
Hydrozincite 296
Hygrophilite 652
Hypersthene 565
Hypochlorite 667
Hypostilbite 612
Hypoxanthite 661
Ice 74
Iceland spar 2 2
Ice spar 589
Ichthyophthalmite 603
Idocrase 4 5
Idrialite 726
Ilmenite 83
Indicolite 466
Inverarite 182
Iodite 5
Iolite 585
Iridium 28
Iridosmium 32
Irite 89
Iron 16
Iserine 84
Ixolyte 712
Jacobsite 87
Jade 578
Jadeite 597
Jalpaite 171
Jamesonite 222
Jarosite 344
Jasper 135
Jeffersonite 569
Jet 51
Johannite 336
Jordanite 236
Joseite 12
Julianite 234
Kainite 357
Kammererite 532
Kaolin 629
Karelinite 255
Karstenite 312
Keilhauite 669
Kermesite 253
Kieserite 390
Kilbrickenite 242
Killinite 5 2 651
Kirwanite 558
Klaprothite 220
Klipsteinite 662
Knebellite 480
Kobaltbeschlag 386
Kobellite 228
Kollyrite 634
Komarit 664
Kongsbergite 23
Konigine 335
Konlite 724
Koppite 681
Kotschubeyite 533
Kottigite 387
Krantzite 713
Kraurite 399
Kreittonite 91
Kremersite 64
Krisuvigite 334
Krokidolite 581
Kuhnite 370
Kupferblau 492
Kyrosite, 140
Labradorite 593
Lanarkite 317
Langite 335
Lanthanite 303
Lapis-lazuli 511
Lasionite 405
Latrobite 591
Laumontite 612
Laurite 204
Lautite 1 2
Lavendulan 386
Lazulite 431
Lead 19
Leadhillite 306
Leadspar 286
Leberkies, 140
Leelite 589
Lenzinite 632
Leonhardite 612
Lepidolite, 518
Lepidomelane 514
Lepolite 591
Lerbachite, 200
Lettsomite 351
Leuchtenbergite 532
Leucite 505
Leucophane 587
Leucopyrite 142
Levyne 610
Lherzolite 567
Libethenite 411
Liebenerite 649
Liebigite 301
Lievrite 483
Lignite 731
Lime mica 522
Limestone 272
Limnite 117
Limonite 110
Linarite 349
Lindakerite 299
Linnæite 152
Liroconite 434
Lithiophilite 369
Lithomarge 631
Lithoxylon 137
Loam 629
Loweite 338
Luchssapphir 585
Lucullite 272
Ludlamite 389
Ludwigite 265
Lumachello 272
Luneburgite 457
Lunnite 423
Luzonite 246
Lydian stone 135
Magnesia mica 512
Magnesio ferrite 86
Magnesite 275
Magnetite 85
Magnolite 354
Malachite 295
Malacolite 567
Malacone 642
Maldonite 196
Mallardite 326
Malthazite 633
Manganese red 2 8
Manganese spar 574
Manganite 109
Manganocalcite 285
Marble 272
Marcasite 140
Marceline 100
Margarite 522
Margarodite 519
Marl 272
Marmolite 550
Martite 82
Mascagnine 309
Masonite 527
Massicot 78
Matlockite 66
Maxite 306
Meerschaum 544
Megabasite 360
Meionite 500
Melaconite 79
Melanite 493
Melanterite 324
Melinophane 588
Mellilite 503
Mellite 704
Melonite 193
Melopsite 631
Mendipite 67
Meneghinite 235
Mengite, 690
Menilite 137
Mercury 20
Mesolite 623
Meteoric iron 16
Miargyrite 212
Mica, 512
Microcline 589
Microlite, 684
Microsommite 507
Miemite 273
Milarite, 573
Millerite 181
Miloschin 635
Mimetesite 446
Minium 104
Mirabilite 318
Mispickel 141
Misy 331
Mixite 425
Mizzonite 501
Molybdenite 203
Molybdite 127
Molysite 61
Monazite, 368
Monradite, 543
Montanite 353
Montebrasite 450
Monticellite 481
Montmorillonite 636
Moonstone 589
Morenosite 323
Morion 135
Morocochite 213
Morvenite 61
Mosandrite 672
Moss agate 135
Mottramite 420
Murchisonite 589
Muriacite 312
Muscovite 519
Mussite 567
Myelin 631
Nacrite 630
Nadorite 702
Nagyagite 195
Naphtha 707
Natrolite 622
Natron 290
Naumannite 173
Needle ore 231
Nemalite 114
Nepheline 506
Nephrite 5 8
Newberyite 378
Newjanskite 31
Nickel, arseniate of 371
Nickelerz 372
Nickelite 183
Nitratine 258
Nitre 253
Nitrocalcite 260
Nitromagnesite 261
Nohlite 698
Nontronite 657
Nosean 509
Ochran 655
Œrstedite 675
Okenite 602
Oligoclase 592
Olivenite 412
Olivine 478
Oncosin 648
Oolite 272
Oosite 585
Opal 136 137
Orangite 645
Orpiment 206
Orthite 474
Orthoclase 589
Osmiridium 31
Ottrelite 528
Oxalite 06
Oxhaveerite 603
Ozocerite 720
Pachnolite 44
Paisbergite 574
Palladium 29
Paraffin 720
Paragonite 520
Pargasite 578
Parisite 305
Paulite 565
Pectolite 598
Peganite 408
Peliom 585
Pennine 532
Pentlandite 182
Percylite 71
Periclase 75
Pericline 590
Peridote 478
Perovskite 680
Petalite 573
Petroleum 707
Petuntze 589
Petzite 175
Phacolite, 608
Pharmacolite 381
Pharmacosiderite, 403
Phenacite 489
Phillipsite 616
Phlogopite 516
Phœnico-chroite 356
Phosgenite 304
Phosphorochalcite 423
Plauzite 711
Pickeringite 341
Picotite 93
Picrolite, 549
Picrophyll 541
Picrosmine 542
Piedmontite 473
Pilolite 580
Pimelite 548
Pinguite 658
Pinite 585
Pinitoid 654
Pisolite 272
Pissophane 332
Pitch blende 90
Pitticite 455
Plagionite 219
Plasma, 135
Platiniridium 27
Platinum 26
Plattnerite 103
Pleonaste 93
Plinthite 655
Plombgomme 442
Plumbocalcite 272
Plumbostib 227
Pollux 606
Polyargyrite 244
Polybasite 243
Polycrase 686
Polydymite 154
Polyhalite 340
Polyhydrite 659
Polymignite 689
Polytelite 239
Porcelain earth 629
Porpezite 25
Potstone 540
Prase 135
Praseolite 585
Prehnite 627
Prosopite 48
Proustite 226
Psilomelane, 121
Psittacinite 374
Pucherite 375
Puffierite 619
Pycnite 463
Pycnotrop 536
Pyrallolite 554
Pyrargillite 585
Pyrargyrite 225
Pyrite 139 140, 151 185 189
Pyroaurite 119
Pyrochlore 684
Pyrochroite 115
Pyrolusite 101
Pyromorphite 444.
Pyrope 493
Pyrophyllite 640
Pyrophysalite 463
Pyropissite 720
Pyroretinite 714
Pyrorthite, 474
Pyrosclerite, 534
Pyrosmalite 529
Pyrostilpnite 252
Pyroxene 567
Pyrrhite 684
Pyrrhotite 151.
Quartz 135
Rammelsbergite, 149
Razoumoffskin 637.

Realgar 205
Reddingite 396
Reddle, 82
Redruthite 164
Reinite 363
Reussite 613
Resins 707-728
Retinite 714
Reussine 337
Rhagite 426
Rhodizite 264
Rhodochrome 532
Rhodonite 574
Ripidolite 533
Rittingerite 187
Rivotite, 703
Rock-crystal 135
Rock salt 51
Rock soap 655
Romanzowite 493
Romeite 700
Roscoelite 678
Roselite 380
Rothoffite 493
Rottisite 664
Rubellan 512
Rubellite 466
Rubicella 93
Ruby 81 93
Rutile 95
Sahlite 567
Salmiac 52
Salt 51
Saltpetre 259
Samarskite 697
Sandbergerite 591
Sanidine 589
Saponite, 548
Sapphire 81
Sapphire d eau 585
Sapphirine 93
Sapphirite 465
Sarcolite 499
Sartorite 214
Sassoline 105
Satin spar 281
Saussurite 597
Savon de verrier 101
Saynite 154
Scapolite 502
Scarbroite 634
Scheelite 361
Scheererite 725
Schiller spar 564
Schirmerite 220
Schneebergite 700
Schneiderite 22
Schorl, 466
Schorlomite 670
Schwartzembergite 68
Scolecite 623
Scorodite 397
Selenite 319
Selenium 3
Selensulphur 2
Senarmontite 124
Serpentine 549
Shale 629
Siderite 135 2
Sideroschisolite, 539
Siderosilicite 661
Siegenite 153
Sillimanite 462
Silver 21
Sinter 137
Sisserskite 32
Skutterudite 157
Slate clay 629
Slate spar 272
Smaltine 145
Smikite 325
Smithsonite 280
Soda chabasite 609
Sodalite 508
Soda mica 520
Spadaite 546
Spar heavy 513
Spathiopyrite, 142
Sphene 668
Spinel 93
Spodumene 572
Stannite 185
Stassfurtite 263
Staurolite 464
Steatite 540
Steinheilite 585
Stephanite 240
Sternbergite 186
Stibiconite 130
Stibnite 208
Stilbite 618
Stilpnomelane 561
Stolpenite 655
Stolzite 362
Strahlstein 578
Strengite 398
Stromeyerite, 165
Strontianite 284
Struvite 428
Studerite 233
Stylotyp 232
Succinite 713
Sulphur 1
Sunstone 592
Surturbrand 731
Susannite 307
Sussexite 271
Svanbergite, 453
Sylvanite, 194
Sylvite 50
Symplesite 385
Syngenite 339
Szaboite 576
Szaibelyite 269
Tabergite 532
Tabular spar 566
Tachhydrite 63
Tagilite 416
Talc 540
Talcosite 640
Tallingite 0
Tantalic ochre 134
Tantalite 691
Tapiolite 692
Telluric bismuth 9
Telluric iron 16
Tellurite 133
Tellurium 4 black 195 graphic 194
Tennantite 238
Tenorite 80
Tephroite 479
Tetradymite 10
Tetrahedrite 237
Tharandite 273
Thenardite 310
Thermonatrite 289
Thomsenolite, 45
Thomsonite 626
Thorite 644.
Thraulite 659
Thrombolite 703
Thulite 472
Thuringite 537
Tiemannite 199
Tilkerodite 161
Tin 15 ores of 98
Tinder ore 129
Tinkal 266
Titanomorphite, 679
Tobermorite 601
Tocornalite 59
Topaz 81 463
Torbanite 727
Tourmaline 466
Travertino 272
Tremolite, 578
Triclasite 585
Tridymite 136
Triphylite 369
Triplite 448
Triploidite 593
Trippkeite 455
Tritomite 646
Trogerite 427
Trona, 291
Troostite 487
Tschewkinite, 671
Tufa, 272
Tungstite 128
Turgite 106
Turnerite 368
Turquoise 404
Tyrite, 695
Tyrolite 422
Ulexite, 268
Ullmannite 148
Umber 661
Uraninite 90
Uranite 436
Uranocircite 438
Uranophane 665
Uranospinite 437
Uranotantalite 697
Uranothorite 644
Uranotile 666
Uran vitriol 336
Urao 291
Urusite 346
Uwarowite 493
Valentinite 125
Vanadine bronzite 568
Vanadinite 445
Variscite 406
Varvicite 101
Vauquelinite 557
Venus hair 95
Veszelyite 413
Villarsite 553
Vitriol, green, 324 red 347 white, 322
Vitriol ochre 331
Vivianite 384
Voglite 300
Volborthite 415
Volgerite 131
Voltaite 342
Voltzine 254
Vulpinite 312
Wad, 121
Wagnerite 447
Walchowite 715
Walkerite 599
Walpurgite 441
Wapplerite 382
Warringtonite 335
Washingtonite 83
Water 74
Wavellite 405
Websterite 329
Wehrlite 11
Weissgiltigerz 239
Weissite 585
Whewellite 706
Whitneyite 192
Willemite 486
Wiserine 366
Withamite 4 3
Witherite 282
Wittichenite 229
Wohlerite 6 6
Wolchite 230
Wolframite 364
Wolfsbergite, 217
Wolkonskoite, 663
Wollastonite, 566
Woodwardite 351
Wulfenite, 358
Wurtzite 178
Xanthocon 251
Xantholite 464
Xanthophyllite 525
Xanthosiderite 111
Xenotime, 366
Xonotlite 600
Xylite 660
Yellow earth 655
Yttrocerite 34
Yttroilmenite 697
Yttrotantalite 694
Yttrotitanite 669
Yu 627
Zaratite 298
Zeagonite 625
Zeolites 598–628
Zepharovichite 406
Zeunerite 440
Zinc 17
Zincite 77
Zinckenite 215
Zinnwaldite, 517
Zircon 138
Zoisite 472
Zorgite 162
Zundererz 132
Zwieselite 449

(M F H)

MINERAL WATERS No absolute line of demarcation can be drawn between ordinary and mineral waters There is usually in the latter an excess of mineral constituents or of temperature, but some drinking waters contain more mineral constituents than others that are called mineral waters, and many very pure waters, both cold and warm, have been regarded for ages as mineral springs

As to the origin of mineral waters, there is much in what the elder Pliny said, that waters are such as the soil through which they flow Thus in limestone and chalk districts an excess of lime is usually present, and the waters of a particular district have much resemblance to each other—as in the Eifel, in Auvergne, and in the Pyrenees But this is only a partial explanation, for waters are by no means necessarily uniform throughout a particular geological formation We do not know with any certainty the depth from which various mineral waters proceed, nor the various distances from the surface at which they take up their different mineral constituents

The source of the temperature of thermal waters remains a subject of much uncertainty Among the assigned causes are the internal heat of the globe, or the development of heat by chemical or electrical agencies in the strata through which they arise

Their occasional intermittence is doubtless often dependent on the periodical generation of steam, as in the case of the Geysers A few geological facts are certain, which bear on the origin of mineral waters Such springs are most abundant in volcanic districts, where many salts of soda and much carbonic acid are present They occur most frequently at meetings of stratified with unstratified rocks, in saddles, and at points where there has been dislocation of strata

The diffusion of mineral waters is very extended Pliny was quite correct in observing that they are to be found on alpine heights and arising from the bottom of the ocean They are found at the snow in the Himalayas and they rise from the sea at Baiæ and Ischia They are to be found in all quarters of the globe, but more particularly in volcanic regions, as in the Eifel and Auvergne, in the Bay of Naples, and parts of Greece, in Iceland, New Zealand, and Japan But there are few countries in which they are not to be found, except in very flat ones and in deltas of rivers,—for instance, in the north of France, where they are very few, and in Holland, from which they are absent France, Germany, Italy, and Spain, as well as Greece, Asia Minor, and the Caucasus, are all rich in mineral waters The British Isles have a fair though not very large proportion of them There are a few in Sweden and Norway They are abundant in the United States, less so in Canada They are found in the Azores and in the West India Islands Of their occurrence in the interior of Africa or of Australia we know little, and the same is true of South America But they are met with in Algiers, in Egypt, and in the Holy Land The vast Indian peninsula has for its size a comparatively small supply

As the effects of mineral waters on the bodily system have been found to be different from those of drinking waters, an explanation of this has been naturally sought for It has been imagined that there is something special in the nature of mineral waters, that their heat is not ordinary heat, that their condition is a peculiar electric one Some French modern writers even say that they have a certain life in them, that their constitution is analogous to that of the serum of the blood But we must pass by these speculations, and be guided as far as possible by ascertained facts, respecting the action on the system of water, of heat and cold, and of the mineral constituents present

Mineral waters, when analysed, are found to contain a great many substances, although some of them occur only in very minute quantities —soda, magnesia, calcium, potash, alumina, iron, boron, iodine, bromine, arsenic, lithium, cæsium, rubidium, fluorine, barium, copper, zinc, manganese, strontium, silica, phosphorus, besides extractive matters, and various organic deposits known under the name of glairin or baregin Of gases, there have been found carbonic acid, hydrosulphuric acid, nitrogen, hydrogen, oxygen, and ammonia Of all these by far the most important in a therapeutic point of view are sodium, magnesia, and iron, carbonic acid, sulphur, and perhaps hydrosulphuric acid These substances, detected separately by chemists, are in their analyses combined by them into various salts, if not with absolute certainty, undoubtedly with a close approximation to it Those combinations are very numerous, and some waters contain ten to twenty of them, but there are always some predominating ones, which mark their character, while many of them, such as cæsium, rubidium, or fluorine, occur in mere traces, and can not be assumed to be of any real importance Mineral waters therefore resolve themselves into weaker or stronger solutions of salts and gases in water of higher or lower temperature For medical purposes they are used either externally or internally, for bathing or for drinking As the quantity of salts present commonly bears but a very small proportion to that of the fluid containing them, water becomes a very influential agent in mineral water treatment, about which it is therefore necessary to say something

For the action of hot and cold baths the reader is referred to the article BATHS But it may be observed here that, according to the most generally received opinion, the cutaneous surface does not absorb any portion of the salts in a mineral water bath, although it may absorb a little gas (an alkaline water, for instance, at most acting as a slight detergent on the skin), and that neither salts nor gases have any action on the system, except as stimulants of the skin, with partial action on the respiratory organs

It seems to be ascertained that drinking considerable amounts of cold water reduces the temperature of the body, diminishes the frequency of the pulse, and increases the blood pressure temporarily Water when introduced into the stomach, especially if it be empty, is quickly absorbed, but, although much of the water passes into the veins, there is no proof that it ever produces in them, as is sometimes supposed, a state of fluidity or wateriness Therapeutically, the imbibition of large quantities of water leads to a sort of general washing out of the organs This produces a temporary increase of certain excretions, augmented diuresis, and a quantitative increase of urea, of chloride of sodium, and of phosphoric and sulphuric acids in the urine Both the sensible and the insensible perspirations are augmented A draught of cold water undoubtedly stimulates the peristaltic action of the intestines On the whole water slightly warm is best borne by the stomach, and is more easily absorbed by it than cold water and warm waters are more useful than cold ones when there is much gastric irritability

In addition to the therapeutic action of mineral waters, there are certain very important subsidiary considerations which must not be overlooked An individual who goes from home to drink them finds himself in a different climate, with possibly a considerable change in altitude His diet is necessarily altered, and his usual home drinks are given up There is change in the hours of going to bed and of rising He is relieved from the routine of usual duties, and thrown into new and probably cheerful society He takes more exercise than when at home, and is more in the open air, and this probably at the best season of the year So important has this matter of season and climate been found that it is an established axiom that waters can be used to the greatest advantage during the summer months and in fine weather, and during the periods most convenient for relaxation from business Summer is therefore the bath season, but of late years provision has been made in many places, with the aid of specially constructed rooms and passages, for carrying out cures satisfactorily during the winter season, *e g*, at Aix la Chapelle Wiesbaden, Baden Baden, Baden in Switzerland, Dax, Vichy, and Bath The ordinary bath season extends from the 15th of May to the 20th or 30th September The season for baths situated at considerable elevations commences a month later and terminates some ten days earlier Mineral waters may be employed at home, but patients seldom so use them, and this necessarily limits the time of their use It is common to declare that the treatment should last for such or such a period But the length of time for which any remedy is to be used must depend on its effect, and on the nature of the particular case It is found, however, that the continued use of mineral waters leads to certain disturbances of the system, which have been called crises, such as sleeplessness, colics, and diarrhœa, and to skin eruptions known as *la poussee* This cause, and also certain peculiarities of the female constitution, have led to the period of three weeks to a month being considered the usual period for treatment A certain after treatment is often prescribed —such as persistence in a particular diet, visiting springs or climates of a different and usually of a tonic character, or continuing for a certain time to drink the waters at home It may be added that the advantage of having recourse to mineral waters is often felt more after than during treatment

Since improved methods of bottling have been discovered, and the advantage of an additional supply of carbonic acid has been appreciated, the export of waters from their sources has increased enormously, and most of the principal waters can now be advantageously used at home It may be added that many of the artificial imitations of them are excellent

The history of the use of mineral waters can only just be alluded to They have been employed from the earliest periods, and traces of Roman work have been found at most of the European baths which are now in favour,—at almost all the thermal ones Occasionally new springs are discovered in old countries, but the great majority of them have been long known They have varied in popularity, and the modes of applying them have also varied, but less so than has been the case with most of the ordinary medicines Warm waters, and those containing small quantities of mineral constituents, appear to have remained more steadily in favour than any other class within the appropriate sphere of mineral waters, which is limited to the treatment of chronic disease

The attempt has been made to range mineral waters according to their therapeutic action, according to their internal or external use, but most generally according to their chemical constituents so far as they have been from time to time understood, and a judicious classification undoubtedly is a help towards their rational employment But their constituents are so varied, and the gradations between different waters are so finely shaded off, that it has been found impossible to propose any one definite scientific classification that is not open to numberless objections Thus a great many of the sulphur waters are practically earthy or saline ones Yet because they contain very minute amounts of such a gas as hydrosulphuric acid, an ingredient so palpable as always to attract attention, it is considered necessary to class them under the head of sulphur The general rule is to attempt to class a water under the head of its predominant element, but if the amount of that be extremely small, this leads to such waters as those of Mont Dore being classified as alkaline or arseniated, because they contain a very little soda and arsenic The classification in the following table, which is that usually adopted in Germany, has the merit of comparative simplicity, and of freedom from theoretical considerations which in this matter influence the French much more than the German writers The more important constituents only are given The amount of solid constituents is the number of parts to one thousand parts of the water, the temperature of thermal springs is added The waters are classified as indifferent, earthy, salt, sulphuretted, iron, alkaline, alkaline saline—with subvarieties of table waters and purging waters

TABLE I —*Typical Mineral Waters*

	Indifferent	*Earthy*	*Salt*	*Salt*	*Sulphur*	*Iron*	*Alkaline*	*Alkaline Saline*	*Table Water*	*Purging Water*
	Gastein 95 118°	Leuk 123 8	Kissingen	Sea Water	Aix la Chapelle, 113 -140°	Schwalbach	Vichy 105° 8	Carlsbad, 119 138°	Selters	Hunyadi Janos
Solids										
Bicarbonate of soda					6449	0206	4 883	1 92	1 2	
,, potash							352			
,, magnesia	0017	013	017	45	0506	2122	303	18		
,, calcium	0195	012	1 06	2 38	157	2213	434	428		
Sulphate of soda	0208	050			2831	0079	292	2 37		15 9
,, potash	0135	038			1527	0037		16		
,, magnesia		308	588	2 96					46	16 0
,, calcium		1 520	389	25						
Sulphide of sodium					0136					
Chloride of sodium	0428		5 52	25 21	2 616		534	1 03	2 2	1 3
,, potash			286							
,, magnesia			303	3 39						
Carbonate of iron	0005	023	0 277			0837		003	01	
Silicic acid	0496	036				0320				
Gases										
Carbonic acid			3 19			5 35	2 6	76	2 24	45
Hydrosulphuric acid					trace					

In addition to their solid constituents, gas is present in many waters in considerable quantity There is a little oxygen and a good deal of nitrogen in some of them, the quantity of hydrosulphuric acid, even in strong sulphuric waters, is wonderfully small, but the volume of carbonic acid present is often very large,—for instance, in the case of Kissingen, Schwalbach, and Selters Carbonic acid is so generally diffused that it is practically a very important agent in the therapeutics of mineral waters Springs that contain it are far the most agreeable to the taste, and consequently most popular with patients The immediate effect of the carbonic acid which they contain is that of pleasant stimulation to the stomach and system, although it can scarcely be said to approach, as some have thought, the slighter forms of stimulation from alcoholic drinks Extremely little appears to be known of its actual operation on the system a part of what is swallowed is returned by eructation, and a part passes on to the intestines, whether any appreciable quantity reaches the blood is doubtful There is no question that carbonic acid increases diuresis Practically it is found to aid digestion, helping the functions of the stomach, and in a slight degree the peristaltic action of the intestines The increased flow of urine may be caused by its favouring the absorption of water by the stomach In some baths carbonic acid is so abundant that precautions have to be taken to prevent its tendency to accumulate on account of its heavy specific gravity Carbonic acid gas, used as a bath, proves stimulating to the skin and to the general system, but its employment has not answered the expectations formed of it

Indifferent Waters scarcely vary in chemical qualities from ordinary drinking water, but they are usually of higher temperature Their therapeutic action, which is mainly exercised through baths, has been explained on the theory of peculiarities of their electric or thermal condition, about which we know nothing definite, and on the presence in some of them of a large quantity of nitrogen It has also been ascribed to the various organic substances in some of them, such as glairin, which when collected is sometimes useful as a cataplasm These waters are not often much drunk, but any efficiency they may have in dyspepsia and perhaps in neuralgic diarrhœas must be attributed to the favourable action of hot water on the digestion The waters of this class, especially the hotter ones in the form of baths, are extremely useful in resolving the effects of inflammation, in thickenings of the joints and in chronic rheumatism and gout They also are often effective, especially the cooler ones, in neuralgia and in some hysterical affections They are sometimes prescribed in urinary affections, in which case they probably assist by dilution The effects of many of these waters are aided by the baths often being situated at considerable elevations and in out of the way spots, whence the Germans called them *Wildbader* They are very widely diffused, being found in all quarters of the globe, especially in volcanic districts There are many in New Zealand, in America the hottest are in the West and in California

TABLE II[1]—*Indifferent Waters*

			what prescribed
Evian Lake of Geneva	1 100		Nervous cases dyspepsia [illegible] affections
Badenweiler Baden	1 425		For mild rheumatic treatment a health resort
Buxton England	0	82	Gout and rheumatism (nitrogen present)
Schlangenbad Nassau	0	80 87	Nervous cases female disorders skin
Sacedon Spain	1 00	85	Rheumatism gout cutaneous affections
Wildbad Wurtemberg	1 320	90 101	Gout and rheumatism neuralgia, [illegible]
Pfeffers Switzerland	2 11	99	Do do do
Ragatz do	1 0	9	Do do do
Panticosa S Pyrenees	5 110	85 95	Do (nitrogen present) special action in phthisis
Teplitz Bohem	648	101 120	Gout rheumatism old injuries joints [illegible]
Gastein Austria		95 118	Do do soothes nervous system

Earthy Waters —These differ chiefly from the indifferent waters in containing an appreciable quantity of salts, among which sulphate or carbonate of lime or of magnesia predominates The great majority of them are of high temperature They produce the same effects as the indifferent waters but are perhaps less efficacious in neuralgic affections, while they are more employed in some of the chronic scaly eruptions There was formerly a tendency to consider these waters useful in urinary affections, but at the present day it is only the colder ones that have come into repute for the expulsion of gravel and biliary calculi and in the treatment of affections of the bladder generally Some of them have also of late years been considered to exercise a favourable influence on scrofula and to be useful in the early stages of pulmorary phthisis This has been attributed to the salts of lime present in them, although it is known that most of its salts pass through the system unaltered Many of these baths, such as Leuk and Bormio, enjoy the advantages of great elevation, but Bath, otherwise one of the best of them, lies low

TABLE III —*Earthy Waters*

Locality	Height in feet	Temp	Therapeutic Action
Contrexeville Vosges	1 (		Special action in calculous affections
Lippe Springe, N Germany			Supposed to be useful in phthisis
Wildungen, do			Special use in urinary complaints contains iron
Weissenberg Switzerland	2 600		Resorted to for pulmonary affections
Pougues France	600		Dyspepsia diabetes hepatic and urinary concretions
Baden Switzerland	1 180	117 122	Rheumatism, gout paralysis scaly eruptions
Leuk do	4 400	93 123	Do some female complaints
Bormio North Italy	4 400	86 104	Do do old sprains
Lucca Italy		108 12?	Do do do
Bath England		108 122	Do do do
Dax south of France	1 400	139	Do do
B de Bigorre Pyrenees	1 800	64–123	Do chlorosis neuralgia.

---

[1] In this and the following tables a selection is given of some of the best known mineral waters in various European countries that possess establishments Their chief peculiarities of elevation of temperature and constituents are briefly noted The curative effects, necessarily alluded to very generally are those usually attributed to them.

Salt Waters are so called from containing a predominant amount of chloride of sodium They also generally contain chlorides of magnesia and of lime and occasionally small amounts of lithium, bromine and iodine They further often contain a little iron, which is an important addition The great majority of the drinking wells have a large supply of carbonic acid There are cold and hot salt springs Sometimes they are used for drinking, sometimes for bathing and the double use of them is often resorted to

The normal quantity of common salt consumed daily by man is usually set down at about 300 grains The maximum quantity likely to be taken at any well may be 225 grains but commonly not more than half of that amount is taken The increase to the usual daily amount is therefore probably not much more than one third Still it may be presumed that the action of a solution of salt on an empty stomach is different from that of the same amount of salt taken with food Salt introduced into the stomach excites the secretion of gastric juice, and favours the peristaltic actions, and when taken in considerable quantity is distinctly aperient We thus see how it is useful in dyspepsia, in atony of the stomach and intestines and sometimes in chronic intestinal catarrh Salt when absorbed by the stomach appears again in the urine of which it increases the amount both of fluid and of solid constituents, especially of the urea It seems therefore to be pretty certain that considerable quantities of salt taken into the circulation increase the excretion of nitrogenous products through the urine, and on the whole accelerate the transformation of tissue Salt is thus useful in scrofula by stimulating the system and also in anæmia, especially when iron is also present In some German stations as at Soden, carbonated salt waters are considered to be useful in chronic laryngitis or granular pharyngitis

Baths of salt water as usually given rarely contain more than 3 per cent of chloride of sodium some of the strongest perhaps from 8 to 10 per cent Their primary action is as a stimulant to the skin in which action it is probable that the other chlorides especially that of calcium and still more the carbonic acid often present co operate In this way, and when aided by various processes of what may be termed water poultices and packing, they are often useful in removing exudations in chronic metritis and in some tumours of the uterus and generally in scrofula and rachitis and occasionally in some chronic skin affections

The French accord high praise to some of their thermal salt waters in paralysis and some German ones are used in a similar way in spinal affections The salt waters are sometimes so strong that they must be diluted for bathing In other cases concentrated solutions of salt are added to make them sufficiently strong These waters are widely diffused but on the whole Germany is richest in them especially in such as are highly charged with salt The Kissingen springs may be considered as typical of the drink ells and sea water of bathing waters The air of salt work pulverization of the water are employed in German baths medial agents

Sal ngs are found in many quarters of the world but the chief nated groups for drinking purposes occur in Germany an la atoga in America where very remarkable wells indeed are to be found France and England have no springs of this e stronger wells used chiefly for bathing occur where there are salt bearing strata, as in Germany, Galicia, Italy, Switzerland, France, and England Very powerful waters of this class are those of St Catherines in Canada

TABLE IV —*Salt Sp* [illegible]

Locality	Temp ° Fahr	Therapeutic Action
ear Frankfort		Dyspepsia anæmia scrofula special for throat and phthisis
g do		Dyspepsia slighter hepatic affections chlorosis gout
Bavaria		In all essentials the same
North Germany		Better known for its iron has a good salt drinking spring
ch near Bingen		A salt well without carbonic acid used in scrofula and anæmia bathing more important
en Nassau	155	Used in dyspepsia and gout the bathing is most important
ider	1 6	Still milder water uses similar gout
ne Haute Marne	114–149	Rheumatism neuralgia effects of malaria
South France	11 [illegible]	Do special for treatment of paralysis
outiers Savoy (1480 ft)	9	Scrofula anæmia loss of power sexual disorders
avoy (1700 ft)	95	Acts on liver and digestive canal used for obesity
orth Italy	109	Rheumatism special treatment with the bath deposit
do	18	Chiefly as baths mud of bath used for poultice
de Mombuy near ona	153–158	Rheumatism sciatica old injuries
Guipuzcoa Spain	88 94	Rheumatism indigestion bronchitis

Almost all the above stations have several springs of various strengths the cold may be said to vary from 14 to 5 8 per cent of chloride of sodium the warm are ker, perhaps varying from 6 8 to 1 6

The presence of minute portions of *iodine* or *bromine* in salt waters is by no means infrequent, and they appear in considerable quantity in some few It is, however, extremely doubtful whether any known spring contains a sufficient quantity of iodine, still more of bromine, to act specially on the system, even if that action were not necessarily superseded by the presence of the large quantity of other salts with which they are associated Some of the best known springs of the kind are —Challes, Wildegg, Castrocaro, Hall, Adelheid s Quelle, Krankenheil, Kreuznach, Woodhall Spa

Iron or Chalybeate Waters —Iron usually exists in waters in the state of protoxide or its carbonate, less frequently as sulphate or crenate, and very rarely if at all as chloride The quantity present is usually extremely small It may be said to vary from 12 to 03 in the 1000 parts of water Some wells considered distinct chalybeates contain less than 03 Many wells, especially in Germany, have a rich supply of carbonic acid, which is unfortunately wanting in French and English ones

It has long been the prevalent idea that want of iron in the blood is the main cause of chlorosis and of other anæmic conditions, and that these conditions are best relieved by a supply of that metal Since the detection of it in hæmoglobuline this view has been still more popular It is pretty certain that the blood contains 37 to 47 grains and the whole system 70 to 74 grains of iron , and it has been calculated that in normal conditions of the system somewhat more than one grain of iron is taken daily in articles of food, and that the same amount is passed in the fæces, for although the stomach takes the iron up it is excreted by the alimentary canal mainly, it being doubtful whether any is excreted in the urine It is possible by drinking several glasses to take in more than a grain of carbonate of iron in the day, equivalent to half that amount of metallic iron It has further been ingeniously reckoned from practice that 10 to 15 grains of metallic iron suffice to supply the deficiency in the system in a case of chlorosis It is thought probable that a portion of the iron taken up in water is in certain pathological states not excreted, but retained in the system and goes towards making up the want of that metal But, whether this or any other explanation be satisfactory, there is no question as to the excellent effects often produced by drinking chalybeate waters (especially when they are carbonated) and by bathing in those which are rich in carbonic acid after they have been artificially heated As regards the drinking cure we must not, however, forget that carbonate and chloride of sodium, and also the sulphate, are often present and must be ascribed a share in the cure Thus chloride of sodium is a power

TABLE V —*Stronger Salt Waters*

Locality	Chloride of Sodium in 1000 parts of Water	Therapeutic Application
Rheinfeld Aargau, Switzerland	311	Scrofula effects of inflammation chronic exudations some chronic exanthemas rheumatism uterine infiltrations
Salzungen North Germany	256	Do do
Ischl Austria (1440 ft)	256	Do do
Hall Tyrol (1700 ft)	255	Do do
Reichenhall near Salzburg (1800 ft)	224	Do do
Bex Rhone Valley (1400 ft)	156	Do do
Castrocaro Tuscany	36	Do do
Droitwich near Worcester	233 6	Do do
Sea Water	30 4	
Rehme Westphalia (92° F)	24 85	Do special use in locomotor ataxia
Nauheim Wetterau (80 103° F)	29	Do do

TABLE VI —*Iron Waters*

Locality	Height in Feet	Carb of Iron	Therapeutic Use
Rippoldsau, Black Forest	1 886	12	For anæmic conditions, laxative
Homburg near Frankfort		10	Do do do
Elster Saxony	1 465	08	Do do do
Liebenstein North Germany	911	08	
Schwalbach Nassau	900	08	Do much of a ladies bath
Bocklet, near Kissingen	600	09	Do
Griesbach Black Forest	1 614	07	Do laxative a ladies bath
Franzensbad Bohemia	1 233	07	Do do do
Pyrmont Germany		07	Do
Spa Belgium	1 000	06	Do
Petersthal Black Forest	1 [illegible]33	04	Do laxative.
St Moritz Engadine Switzerland	5 464	03	Do , sought for its air
Forges les-Eaux France		06	Do
La Malou Hérault, France (temp 88°)		09	Do
Recoaro North Italy	1 463	04	Do
Tunbridge Wells England		06	Do deficient in carbonic acid.
Muspratt Spring, Harrogate (chloride)		15	

ful adjuvant in the strong Stahl Quelle of Homburg and in the Putnam Well at Saratoga A whole category of female complaints is treated successfully with these waters Indeed anæmia from any source, as after fever or through loss of blood, and enlargements of the spleen, are benefited by them The stimulating action of the copious supply of carbonic acid in steel baths is a very important adjuvant, no one now believes in direct absorption of iron from the bath Iron waters are scarcely ever thermal They are extremely common in all countries,—frequently along with sulphuretted hydrogen in bogs, and near coal measures But such springs and non carbonated wells generally are weak, and not now held in much esteem

It may be added that some of the strongest known iron wells are *sulphated* or *aluminated* They are styptic and astringent, and can only be used diluted They are sometimes useful as an application to ulcers and sores Such springs have often been brought into notice, but never retain their popularity They are known in the Isle of Wight, in Wales, in Scotland, as well as in Elba, &c , and of late years the Bedford Alum and Oak Orchard Springs, U S , have been brought into notice the latter containing 10 grains of free sulphuric acid in the pint All such springs have been considered useful in scrofula, anæmia, and chronic diarrhœas

Sulphur Springs —Waters having the odour of hydrosulphuric acid however slightly, are usually called sulphur ones They owe their smell sometimes to the presence of the free acid, sometimes to sulphides of sodium, calcium or magnesia, and sometimes to both Hydrosulphuric acid is absorbed more freely by cold than by hot water, and is therefore most abundant in cold springs The sulphides decompose and give off the gas Most of these springs occur near coal or shale measures or strata containing fossils or in moors and in places generally where organic matter is present in the soil or strata Many of them contain so little mineral impregnation that they might as well be classed among the indifferent or earthy waters One group contains a considerable amount of chloride of sodium another of sulphate of lime, while a third has little mineral impregnation but contains sulphides

Hydrosulphuric acid is a strong poison and its action on the system has been pretty well ascertained It has been assumed that the gas in mineral waters acts similarly, though in a modified degree, but there is next to nothing absolutely known of the action of the small quantities of the gas that are present in mineral waters and which certainly have no toxic effect It has been assumed that this gas has some special action on the portal system and so on the liver On the connexion of metallic poisoning with the liver has been founded the idea that sulphur waters are useful in metallic intoxication Drinking large quantities of these waters, especially of such as contain sulphates or chlorides of sodium or magnesia combined with hot baths and exercise may help to break up albuminates but there is no proof of the action of the sulphur

For similar reasons and primarily to counteract mercurial poison, sulphur waters have been considered useful in syphilis But it may be well to remember that at most baths mercury is used along with them No doubt they are frequently, like other warm waters useful in bringing out old eruptions, acting in this way as a test for syphilitic poison, and in indicating the treatment that may be required Sulphur waters, both hot and cold, are used in gout and rheumatism, in dyspepsia, in hepatic and cutaneous affections, and of late years inhalation of them has been popular in phthisis and in laryngeal affections They have long been popular remedies in cutaneous affections While so much doubt has been cast on the action of the sulphur of these waters, it may be admitted that the sulphides are probably decomposed in the stomach and hydrosulphuric acid generated That gas is probably a slight stimulant to the intestine What hydrosulphuric acid reaches the blood is eliminated by the lungs There seems to be no doubt that the gas is absorbed in small quantities by the skin

It is in sulphur waters chiefly that glairin and baregin occur This peculiar organic substance has been found both in American and in European springs Cold sulphur springs are very widely diffused throughout the world Thermal ones are not so common Perhaps the largest though not the strongest group of the latter is to be found in the Pyrenees We may remark again how very little hydrosulphuric acid there is in many of the most favourite sulphur springs, including the very popular White Sulphur ones of Virginia There seems to be something peculiarly unsatisfactory in the analysis of sulphur waters, and there has been difficulty in constructing the following imperfect tables

Some of the most powerful cold wells are those of Challes (with its very peculiar water) Leuk, and Harrogate Uriage has a very large amount of chloride of sodium in its springs Cold sulphur waters are on the whole more used in liver and indigestion than warm ones The general effects of warm sulphur waters differ so little at the various baths as to make it difficult to mention anything special to particular localities Schinznach has a reputation in skin complaints Cauterets Eaux Bonnes, and Challes in laryngeal affections, the two Aixes, Luchon, and Archena in syphilis

Alkaline Waters are such as contain carbonate (chiefly bicarbonate) of soda along with an excess of carbonic acid Of the action of those carbonates it is known that when taken into the stomach they are neutralized by the gastric juice, and converted into chloride of sodium On their introduction into the stomach they produce an increased flow of gastric juice If given during or immediately after meals in any quantity they impede digestion They slightly increase peristaltic action but only feebly unless assisted by other salts They act slightly as diuretics Of the connexion between the biliary system and alkalies which undoubtedly exists, not much is known with certainty The alkalization of the blood by them is assumed by many, but not proved It is very doubtful whether they reduce the quantity of fibrine in the blood, and thus induce a

TABLE VII —*Cold Sulphur Springs*

Locality	Hydrosulphuric Acid absorbed in Water	Sulphide of Sodium
Eilsen Schaumburg Lippe	42 [illegible]	
Meinberg Lippe Detmold	[illegible]3 1	008
Gurnigel, Switzerland (3[illegible]00 ft)	1 1	
Leuk do ([illegible]93 ft)	44 5	
Challes Savoy ([illegible]00 ft)		4 8
Enghien near Paris		106
Uriage Isère France (1[illegible]00 ft)	7 34	
Harrogate England		20
Strathpeffer Scotland		0[illegible]6
Lisdunvarna Clare Ireland		

TABLE VIII —*Warm Sulphur Springs*

			Hydrosulphuric Acid absorbed in Water
Aix la Chapelle Germany			
Baden near Vienna			
Schinznach Switzerland	1 060		
Lavey Rhone Valley	1 [illegible]0		
Hercules Bad Banat	[illegible]		
Aix les Bains Savoy			
Luchon Pyrenees			
Baréges do			
Amélie les Bains Pyrenees		87 147	
Cauterets, do		71 134	
Eaux Bonnes do		90 5	
Archena Murcia Spain			

TABLE IX —*Alkaline Waters*

s I *Simple Alkaline*

	(Catarrh of stomach gout renal a
Bilin Bohemia	
Vichy France (10 F)	
Neuenahr Rhineland (9 97 F)	s catarrh diabetes specially
La Malou France (97 F)	
Vidago Portugal	Do gout urinary affectio Portuguese Vichy

				Therapeutic Use
Luhatschowitz Mo				Springs rich both in carb soda and chl sodium Light antacid tonic to stomach
Ems Nassau		8[illegible]–11[illegible]		Special in female complaints and mucous membrane
Ischia Italy				Specially rheumatism and female complaints
Royat, Auvergne	1 400	80–95	1 3	Do and some skin affections
Mont Dore do	[illegible] 300	100 114		Asthma chronic laryngitis
Bourboule do	2 80			Scrofula rachitis cuta

s III —*With Sulphate of Soda varying from 5 2 to 2 in a*
Carbonate of Soda varying from 3 [illegible] to 51 in amou

Locality	Height in Feet	Therapeutic Uses
Elster Saxony	1 460	Action on abdominal female complaints
Marienbad Bohemia	1 012	Do special use in obesity
Franzensbad do	1 293	Do specially a ladies bath
Tarasp Lower Engadine	4 000	Powerful action on abdominal viscera.
Carlsbad, Bohemia (121°–164° F)		Gout liver affections biliary and renal calculi diabetes

lowered state of the system, or whether they have any direct tendency to combine with fat and carry off a portion of superfluous adipose tissue. Their excess of carbonic acid, through its action on the stomach, favours the operation of alkaline waters. They have been classed as follows:—(I.) simple alkalines, where carbonate of soda is the main agent; (II.) waters containing in addition some chloride of sodium; (III.) waters containing sulphates of soda or of magnesia. All these classes may be said to be used in gout, lithiasis, affections of the liver, catarrh, and obstructions of the gall ducts, in dyspepsia, chronic catarrh of the stomach, and diarrhœa, in obesity, and in diabetes. Some of the waters of the second class are supposed to influence bronchial catarrhs and incipient phthisis, while the more powerful sulphated waters of the third class are especially useful in catarrh of the stomach, and in affections of the biliary organs; of these only one of importance (Carlsbad) is thermal. The rival cold waters of Tarasp contain twice as much carbonate of soda. The cold ones are chiefly used internally, the thermal ones both internally and externally. The latter, besides acting as warm water, slightly stimulate the skin when the carbonic acid is abundant, and the carbonate of soda has some slight detergent effect on the cutaneous surface like soap. These waters are unknown in England. They are most abundant in countries of extinct volcanoes.

Classes I. and II. of alkaline waters may be said to have a sub-variety in *acidulated* springs or carbonated waters, in which the quantity of salts is very small, that of carbonic acid large. These table waters are readily drunk at meals. They have of late years been so widely exported as to be within the reach almost of every one. Their practical importance in aiding digestion is in reality much greater than one could expect from their scanty mineralization. They are drunk by the country people, and also largely exported and imitated. They are very abundant on the Continent, and although some of the best known ones enumerated below are German and French, they are common in Italy and elsewhere:—Heppingen, Roisdorf, Landskro, Apollinaris, Selters, Bruckenau, Gieshubel (all German); St Galmier, Pougues, Chateldon, French.

Associated with Class III. is that of the strongly *sulphated* waters known in Germany as bitter or purging waters, which have of late deservedly come into use as purgative agents. They are almost wanting in France and in America, and there are no very good ones in England. The chief supply is from Bohemia and Hungary. The numerous waters of Ofen are the best known, and some of them are stronger than the Hunyadi, of which an analysis has been given in Table I. They are easily imitated. Some of the best known are Ofen, Pullna, Saidschutz, Friedrichshall, Birmerstorff, Kissingen.

Two other classes of waters demand a few words of notice. The French have much faith in the presence of minute quantities of arsenic in some of their springs, and trace arsenical effects in those who drink them, and some French authors have established a class of *arsenical* waters. Bourboule in Auvergne is the strongest of them, and is said to contain 1/10th of a grain of arseniate of soda in 7 ounces of water. Baden Baden, according to Bunsen's latest analysis, has a right to be considered an arsenical water. It is, however, extremely doubtful whether the small amounts of arseniate of soda which have been detected, accompanied as they are by preponderating amounts of other salts, have any actual operation on the system. The following are among the most noted springs:—Bourboule, Mont Dore, Royat, Salies (Bigorres), Plombières, Baden Baden.

Of late years *lithium* has been discovered in the waters of Baden Baden, and various other places boast of the amount of that substance in their springs. Indeed a new bath has been established at Assmannshausen on the Rhine in consequence of the discovery of a weak alkaline spring containing some lithium. Not very much is known of the action of lithium in ordinary medicine, and it undoubtedly does not exist in medicinal doses even in the strongest springs. Among these springs are those of Baden Baden, Assmannshausen, Elster, Royat, Ballston Spa, and Saratoga (U.S.).

AMERICAN MINERAL WATERS.—The number of springs in the United States and Canada to which public attention has been called on account of their supposed therapeutic virtues is very large, amounting in all to more than three hundred. Of this number comparatively few are in Canada, and of these not more than six (St Catharines, Caledonia, Plantagenet, Caxton, Charlottesville, and Sandwich) have attained general celebrity. The first three belong to the saline class, the Caxton is alkaline saline, and the last two are sulphur waters. The St Catherines is remarkable for the very large amounts of sodium, calcium and magnesium chlorides which it contains, its total salts (450 grains in the pint) being more than three times the quantity contained in the brine baths of Kreuznach in Prussia. The Charlottesville and Sandwich springs likewise surpass the noted sulphur waters of Europe in their excessive percentages of sulphuretted hydrogen, the former containing more than 3 and the latter 4.72 cubic inches of this gas in the pint.

The mineral springs in the United States are very unequally distributed, by far the larger number of those which are in high medical repute occurring along the Appalachian chain of mountains, and more especially on or near this chain where it passes through the States of Virginia, West Virginia, and New York. The Devonian and Silurian formations which overlie the Eozoic rocks along the course of the Appalachian chain have been greatly fissured—the faulting of the strata being in some places of enormous magnitude—by the series of upheavals which gave rise to the many parallel mountain ridges of the Appalachians. In many places the springs occur directly along the lines of fault. The various classes of mineral waters are likewise very unequally represented, the alkaline springs, and those containing Glauber and Epsom salts, being much inferior to their European representatives. On the other hand, the very numerous and abundant springs of Saratoga compare very favourably with the Selters and similar saline waters, and among the many American chalybeate springs the subclass represented by the Rockbridge Alum is unequalled in regard to the very large percentages of alumina and sulphuric acid which it contains. Besides its greater amount of mineral constituents (135 grains per pint), the Ballston spring surpasses the similar saline waters of Homburg, Kissingen, Wiesbaden, and Selters in its percentage of carbonic acid (53 cubic inches). It is also remarkable for the very large proportion of carbonate of lithia, amounting to 0.701 grains. Thermal springs are specially numerous in the territories west of the Mississippi and in California. Those in the east mostly occur in Virginia along the southern portion of the Appalachian chain; in the middle and New England States Lebanon is the only important thermal spring. Subjoined is a list of thirty American springs, the design being to represent as many of the more noted spas as possible, while at the same time enumerating the best representatives of the classes and subclasses into which mineral waters are divided according to the German method of classification.

	Designation and Locality	Therapeutic Application
Indifferent (Thermal)	Lebanon, Columbia Co., N.Y. (73° F.)	
	Healing, Bath Co., Va. (88° F.)	Scrofulous ulcers and ophthalmia, ozæna, chronic diarrhœa and dysentery, secondary and tertiary syphilis
	Warm, Bath Co., Va. (98° F.)	Chronic and subacute rheumatism, gout, neuralgia, nephritic and calculous diseases
	Hot, Bath Co., Va. (110° F.)	Chronic rheumatism, gout, diseases of liver, neuralgia, contractions of joints
	Paso Robles, San Luis Obispo Co., Cal. (122° F.)	
	Hot, Garland Co., Ark. (93°-150° F.)	Dartrous diseases of skin, functional diseases of uterus, chronic mercurial and lead poisoning
Calcareous and Earthy	Gettysburg, Adams Co., Penn.	Calculus, gravel, catarrh of stomach or bladder, dyspepsia
	Sweet, Monroe Co., W. Va. (74° F.)	Gravel, dyspepsia (diuretic, diaphoretic)
	Berkeley, Morgan Co., W. Va. (74° F.)	Neuralgia (restorative)
	Alleghany, Montgomery Co., Va.	Purgative, diuretic
	Bethesda, Waukesha Co., Wis.	Diabetes mellitus, gravel, inflammation of bladder, dropsy, albuminuria (diuretic)
Sulphur	Lower Blue Lick, Nicholas Co., Ky.	Aperient and alterative
	Sharon, Schoharie Co., N.Y.	Do. do.
	White Sulphur, Greenbrier Co., Va.	Dartrous skin diseases, diseases of the bladder, jaundice, dyspepsia
	Salt Sulphur, Monroe Co., W. Va.	Do., scrofula and syphilis
Epsom Salt	Bedford, Bedford Co., Penn.	Anæmia, gravel, calculus (strongly diuretic)
Common Salt	St Catherines, Ontario, Canada	Rheumatism, gout, scrofula, neuralgia
	Caledonia, Ontario, Canada	Rheumatism, gout
	Hathorne, Saratoga, N.Y.	Dyspepsia, jaundice, abdominal plethora
	Ballston, Saratoga Co., N.Y.	Do. do. do.
Iron	Oak Orchard Acid, Genesee Co., N.Y.	Ulcers, diseases of the skin, passive hæmorrhage, atonic diarrhœa (has 10 grains of free sulphuric acid in the pint)
	Pawley, Rockingham Co., Va.	Chlorosis and anæmia, generally tonic
	Sweet Chalybeate, Alleghany Co., Va.	Do. do. do.
	Rockbridge Alum, Rockbridge Co., Va.	Scrofula, chronic diarrhœa
	Cooper's Well, Hinds Co., Miss.	Anæmia, chlorosis, chronic diarrhœa, dropsy
Glauber Salt	Crab Orchard, Lincoln Co., Ky.	
	Midland, Midland Co., Mich.	
Alkaline	Bladon, Choctaw Co., Ala. (carbonated alkaline)	
	Congress, Santa Clara Co., Cal. (saline alkaline)	
	St Louis, Gratiot Co., Mich. (simple alkaline)	Dyspepsia, neuralgia, chronic and subacute rheumatism

Bibliography.—1. German: I. Osann, *Darstellung der Heilquellen Europas*, 3 vols., Berlin 1839-43; J. Seegen, *Handbuch der Heilquellenlehre*, Vienna 1862; B. M. Lersch, *Hydrochemie* 1870 and many other works; Helfft, *Handbuch d. Balneotherapie*, 8th ed., Berlin 1874; Valentiner, *Handbuch d. Balneotherapie*, Berlin 1876; L. Lehmann, *Bäder u. Brunnen Lehre*, Bonn, 1877; J. Braun, *System. Lehrbuch d. Balneotherapie*, 4th ed. by Fromm, Berlin 1880; O. Leichtenstern, *Balneotherapie*, Leipsic 1880. 2. French: *Dictionnaire des Eaux minérales* &c. by MM. Durand-Fardel &c., 2 vols., Paris 1860; J. Lefort, *Traité de Chemie Hydrolologique*, 2d ed., Paris, 1873; C. James, *Guide Pratique aux Eaux*

minerales Paris (many editions), Macé *Guide aux Villes d'Eaux* &c Paris 1881, Joanne and Le Pileur *Les Bains d Europe* Paris 3 Swiss Meyer Ahrens *Heilquellen der Schweitz* Zurich 1867 Gsell Fels *Die Bader und Kurorte der Schweitz* Zürich 1880 4 Italian G J rvis *Guida alle Acque Minerali d Italia* Turin 1876 &c E F Harless *Die Heilquellen und Kurbader Italiens* Berlin 1848 5 Spanish Rubio *Tratado de las Fuentes Minerales de Espana* Madrid 1853 Don J de Antelo y Sanchez has recently published a work on Spanish waters 6 English T Short *History of the Mineral Waters* London 1734 Rutty *Methodical Synopsis of Mineral Waters* London 1757 Granville *Spas of England* 1841 E Lee *Mineral Springs of England* London 1841 J Macpherson *Our Baths and Wells* 1871 Id *Baths and Wells of Europe* 1873 and Weber s English edition of Braun London 1875 A great portion of the literature is to be found in monographs on particular places 7 American J Bell *The Mineral and Thermal Springs of the United States and Canada* 1855 Moorman *The Mineral Waters of the United States and Canada* 186 Chandler *Lecture on Water* 1871 Walton *The Mineral Springs of the United States and Canada* 1875
(J M—A R L)

MINERVA (*i e*, *menes va*, endowed with mind) was the Roman goddess who presided over all handicrafts, inventions, arts, and sciences She was probably an Etruscan deity, but her character was modified on Roman soil through her identification with the Greek Pallas Athena (see ATHENA) No legend of her birth is recorded, the Roman deities were abstractions, not distinct persons with an individual history Her chief worship in Rome was in the temple built by Tarquin on the Capitol, where she was worshipped side by side with Jupiter and Juno This foundation may be assigned to Etruscan influence She had also an old temple on the Aventine which was a regular meeting place for dramatic poets and actors The dedication day of the temple and birthday of the goddess was March 19, and this day was the great festival of Minerva, called *quinquatrus* because it fell on the fifth day after the Ides The number five was sacred to the goddess All the schools had holidays at this time, and the pupils on reassembling brought a fee (*minerval*) to the teachers In every house also the *quinquatrus* was a holiday, for Minerva was patron of the women s weaving and spinning and the workmen s craft At a later time the festival was extended over five days, and games were celebrated This feature is evidently due to the Græcizing conception of Minerva as the goddess of war To this same Græcizing tendency we must attribute the *lectisternium* to Minerva and Neptune conjointly after the battle of the Trasimene Lake The 23d had always been the day of the *tubilustrium*, or purification of the trumpets, so that the ceremony came to be on the last day of Minerva s festival Trumpets were used in many religious ceremonies, and it is very doubtful whether the *tubilustrium* was really connected with Minerva There was another temple of Minerva on the Cælian Hill, and a festival called the lesser *quinquatrus* was celebrated there on June 13–15, chiefly by the flute players

Minerva of the Cælian temple was called Capta, June 19 was the foundation day of this temple and the birthday of the goddess The *palladium*, an archaic image of Pallas was brought from Troy to Lavinium and thence to Rome by the family of the Nautii it was preserved in the temple of Vesta as a pledge of the safety of the city There are some traces of an identification of Minerva with the Italian goddess Nerio wife of Mars it is probable that March 19 was originally a feast of Mars

Besides Preller *Rom Myth* and Hartung *Relig d Romer* &c see Jordan *Ephem Epigraph* i 38 Mommsen *C I L* i 388 Usener *Rhein Mus* xxx 222

MINGRELIA, a former principality of Transcaucasia, which became subject to Russia in 1804, and since 1867 has constituted three circles of the government of Kutais—Letchgum, Senakh, and Zugdidi The country corresponds to the ancient Colchis, and Izgaur or Iskuriah on the Black Sea coast, which was the capital during the period of Mingrelian independence under the Dadian dynasty, is to be identified with the ancient Dioscurias, a colony of Miletus The Mingrelians (still almost exclusively confined to the Mingrelian territory, and numbering 197,000) are closely akin to the Georgians See CAUCASUS, vol v p 257, and GEORGIA

MINIATURE is a term which by common usage has come to be applied to two different branches of painting Derived from the Latin word *minium*, the red pigment used in the primitive decoration of MSS, in the first place it is the technical word employed to describe a painting in a MS, and, from the fact of such pictures being executed on a reduced scale, it has its secondary and modern signification of a small, or miniature, portrait In the latter sense it belongs to the general subject of painting Here it is proposed to trace the development of the miniature in MSS of the different schools of Europe

The rise of the art of ILLUMINATION, in which the miniature plays so important a part, has been described under that heading, and something has been said in that place about the earliest extant specimens of miniature painting Unfortunately we cannot with any certainty reach farther back than the 4th century for the most ancient of them, and all remaining examples between that period and the 7th century in Greek and Latin MSS can be counted on the fingers The two famous codices of Virgil in the Vatican Library stand pre eminent as the most ancient Latin MSS decorated with paintings The miniatures in the first of them, the *Codex Romanus*, are large and roughly yet boldly executed paintings, which have no pretension to beauty, and are simply illustrations, but they are as old as the 4th century, and are of the highest value in enabling us to appreciate the debased style to which classical art had descended, and which no doubt was more largely employed than we might think The second MS, the *Schedæ Vaticanæ*, which may also be assigned to the 4th century, is far more artistic and retains a good deal of the grace of classic art Of the same kind, but of rather later date, are the fragments of the *Iliad* in the Ambrosian Library at Milan, the miniatures of which are generally of excellent design Next comes the Dioscorides of the Imperial Library at Vienna, with its semiclassical portrait miniatures executed at the beginning of the 6th century Of a rather later period are the paintings which illustrate the Greek MS of Genesis in the same library A far finer and older MS of the same book of the Pentateuch once existed in the Cottonian Library, but was almost totally destroyed by fire The few fragments of the miniatures which once filled this volume, and which were of the 5th century, are sufficient to show what excellent work could be done in the capital of the eastern empire, from whence the MSS most probably came The late interesting discovery of an illustrated MS of the Gospels in Greek, of the latter part of the 6th century, at Rossano in southern Italy, adds another number to our scanty list of early volumes of this class, which is closed by the Latin Pentateuch in the library of the earl of Ashburnham This last MS, however, is not older than the 7th century It was executed in Italy, and is adorned with many large miniatures, not of high artistic merit, but of great interest for the history of painting and of costume

Coeval with the MSS which have just been enumerated are the beautiful mosaics and wall paintings which are seen at Rome, Ravenna, and in other parts of Italy, serving as standards of comparison and carrying on the history of art where MSS fail us The strong and ever increasing Byzantine element which appears in these works prepares us to find the predominance of the same influence when we again pick up the broken thread of the history of miniature painting We may then, at this point, turn for a moment to the east of Europe and state briefly what remains of Greek art in MSS Of Greek miniatures there are still many fine examples extant, but, excepting those which have been noticed above, there are few which are earlier than the 11th century At this period the miniature appears in the set form which it retained for the next two or three hundred years, and the connexion between its style and that of the mosaics is too evident for us to be at a loss to explain the course of development. The figure drawing is delicate, but rather exaggerated in length, the colours are brilliant, and the whole effect is heightened by glittering backgrounds of gold. In some few instances, however, the Greek artist breaks away from conventionalism, and, especially when pourtraying the divine features of the Saviour or some subject which deeply stirs his feelings, he surprises us with the noble dignity with which he invests his figures. Minuteness also caught the fancy of these Byzantine miniaturists, and there still remain MSS., such as Psalters and saints' lives, adorned throughout with delicate little drawings of great symmetry and beauty. The ornamentation which was employed in Greek MSS. in the period of which we are speaking, either as frames for miniatures or as borders or head pieces, is designed evidently after Eastern types, and has more than an accidental likeness to the patterns which are seen in the tapestries and prayer carpets of Persia. After the 13th century decadence sets in, and we need not follow the course of Byzantine art in MSS. farther than to notice that immediately from it sprang such national styles as those of Russia, Bulgaria, and modern Greece.

Meanwhile, in the West, under the fostering care of Charlemagne, arose a great school of decoration in MSS., which at the close of the 8th and beginning of the 9th century were multiplied and enriched with all the splendour that colours and gilding could give to them. But the books thus ornamented were almost always copies of the Gospels, or Bibles, or church service books, which afforded little scope for invention. Hence among the miniatures of this period we have an endless repetition of portraits of the evangelists, drawn, for the most part, in a lifeless way after Byzantine traditions, and degenerating, as time passes, into positive ugliness. The few miniatures of other descriptions, such as Biblical illustrations, show no great merit, and a half barbaric splendour was generally preferred to artistic effect. But an exception must be made in regard to the style of drawing found in the MS. known, on account of its present resting place, as the Utrecht Psalter. This volume is filled from beginning to end with delicately drawn pen illustrations, designed and executed with a facility which, compared with the mechanical and clumsy drawing of other Continental MSS. of the period, is astonishing. And these drawings are of particular interest for us, as they are of the style which was adopted in England and which gives to Anglo-Saxon art its distinctive aspect. Executed about the year 800 or early in the 9th century, and probably in the north of France, the volume was soon brought to England, where, however, MSS. of the same kind, it may be assumed, had long before been introduced. The light "fluttering" outlines of the drapery and other details of the drawings seem to suggest that the original models were derived directly from Roman life, and perhaps partly copied from sculpture, but those models must have gone through many modifications before passing into the style of the drawings of the Psalter. That the MS. was copied from an older one there can be scarcely a doubt, and it is not impossible that the original archetype may date back some centuries earlier. May not MSS. which St Augustine and his successors brought from Rome have contained drawings of the same kind? This style of drawing was, at all events, adopted and became nationalized in England, but it had there a rival in the Irish school of ornamentation, introduced from the north of the island. The early civilization of Ireland placed her in the van of art development in these islands. The wonderfully intricate interlaced designs which render Irish MSS. of the 7th and 8th centuries such marvels of exact workmanship derive their origin, in all probability, from the metal work of earlier ages. But, apart from ornamentation, the Irish miniatures of saints and evangelists are extraordinary and grotesque instances of purely mechanical drawing, which cause us to wonder how the same eyes and hands which assisted in the creation of such beautiful specimens of pure ornament could tolerate such caricatures of the human shape. The explanation is perhaps to be found in superstitious regard for tradition. This style of art was carried by the monks to Iona and thence to Lindisfarne, where was founded the school which produced, in the 8th and 9th centuries, the richly ornamented codices of Durham. While, then, Byzantine models were copied on the Continent, the free drawing introduced from the south and the intricate ornamentation brought in from the north were practised in England, but the free drawing, with its accompanying decoration copied from foliage, and gradually developing into beautiful borders harmoniously coloured, gained the day, and lasted down to the time of the Norman Conquest. The one great fault of this latter style of drawing strikes the eye at the first glance. This is the inordinate length of limb with which the human figures are endowed. But this blemish is forgotten when one comes to appreciate the many points of merit in the designs.

In Italy, after a long period of inactivity, two very different styles of decoration of MSS. sprang into existence. The first of these was that of the Lombardic school, which is distinguished by intricate patterns and bright colouring. The large initial letters which are found in the MSS. of the 11th and 12th centuries, the best period of this style, are often a perfect maze of interlaced bands and animal forms, and are extremely handsome and effective. Figure drawing however, seems to have been but little practised by the Lombardic artists, but such as there is appears on a broad scale and well executed. In the collections of Monte Cassino are some of the best examples of this school. In the second style which developed in Italy the Byzantine influence is at first most marked. Indeed, among its early specimens of the 13th century are some which might pass for the work of Greek artists. But the genius of the Italians soon assimilated the foreign element, and produced a national school which spread throughout the peninsula and afterwards extended its influence to southern France and Spain. It is, however, remarkable that in a country which produced such fine pictures and wall paintings at an early date there is comparatively little miniature painting in contemporary MSS. A curious and early instance of this kind of art occurs in a MS. in the British Museum, written and ornamented with a series of miniatures at Winchester, in the 12th century, in which are two paintings which are purely Italian and of more than ordinary excellence.

In the majority of the extant Italian miniatures of the 14th century the influence of the great artists of the Florentine school is manifest. The peculiar treatment of flesh tints, painted in body colour over a foundation of olive green, and the peculiar vermilion and other colours which need be but once seen to be ever afterwards recognized as belonging to this school, are constantly present. The figures are generally rather shortened and the drapery carried in straight folds, very different characteristics from the swaying figures and flowing drapery of the English and French artists of the same period. The ornamentation which accompanied this style of miniature generally consists of heavy scrolls and foliated or feather-like pendants from the initial letters, with spots of gold set here and there in the border. There are also extant some examples of a most beautiful kind of ornamentation which appears to have originated in central Italy, and which seems to partake of the qualities of both the styles of Italian art of which we have been speaking, combining the drawing of the Florentine school with a lighter colouring which may have been suggested by the Lombardic

Of native Spanish miniature art little can be said. In the Visigothic MSS. of the early Middle Ages there is no ornament beyond roughly coloured initial letters and some barbaric figure drawing. A little later, however, we get some indication of national peculiarities in the MSS of the 10th, 11th, and 12th centuries. Here there appear miniatures, stiff and rude in their drawing, but exhibiting the unmistakable Spanish predilection for sombre colours, —dusky reds and yellows and even black entering largely into the compositions

The materials at our disposal of the 10th, 11th, and 12th centuries show the gradual development in France and western Germany of a fine free hand drawing which was encouraged by the proportionately increasing size of books Both in outline and colour the fully developed miniatures of the 12th century are on a grand scale, and initial letters formed of scrolls and interlacings assume the same proportions The figure drawing of this time is frequently of great excellence, the limbs being well proportioned, care is also bestowed upon the arrangement of the drapery, which is made to follow the shape and, as it were, to cling to the body

But the great revulsion from the broad effects and bold grandeur of the 12th century to the exact details and careful finish of the 13th century is nowhere more striking than in miniature painting in MSS With the opening of the new period we enter on a new world of ideas Large books generally disappear to give place to smaller ones, minute writing supersedes the large hand, and miniatures appear in circumscribed spaces in the interior of initial letters The combination of the miniature with the initial brings it into close connexion with the ornamental border, which develops *pari passu* with the growth of the miniature and by degrees assumes the same national and distinctive characteristics Burnished gold was now also freely used, tending to give the miniature a more decorative character than formerly In England, northern France, and the Netherlands the style of miniature painting of this period was much the same in character, and it is often difficult to decide from which of these countries a MS is derived. English work, however, may be often distinguished by its lighter colouring, while deeper and more brilliant hues and a peculiar reddish or copper tinge in the gold marks French origin. The drawing of the Flemish artists was scarcely so good, the outlines being frequently heavy and the colours rather dull Of the Rhenish or Cologne school examples are more scarce, but they generally show greater contrasts in the colours, which, though brilliant, are not so pleasing As the century advanced, and particularly at its close, national distinctions became more defined English artists paid more attention to graceful drawing and depended less upon colour. In some of their best productions they are satisfied with slightly tinting the figures, finding room in the backgrounds for display of brilliant colours and gilding In France the drawing, though exact, is hardly so graceful, and colour plays a more important part From the 13th to the middle of the 15th century great decorative effect is obtained by the introduction of diapered or other highly ornamented backgrounds. Of landscape, properly so called, there is but little, a conventional hill or tree being often taken as sufficient indication. Borders begin in the 13th century in the form of simple pendants from the initial letters, terminating in simple buds or cusps But once arrived fairly in the 14th century, a rapid development in all parts of the decoration of MSS takes place There is greater freedom in the drawing, the borders begin to throw out branches and the bud expands into leaf This is the best period of English miniature painting, many of the fine MSS. of this century which are preserved in the public libraries bearing witness to the skill and delicate touch of native artists In France the decoration of MSS received a great impetus from the patronage of King John and Charles V, of whose famous libraries many handsome volumes are still to be seen, and later in the century the duke of Berri carried on the same good work

With regard to miniature art in Germany there are so few examples to guide us that little can be said Most of them are rough in both drawing and colouring, and in the few remaining specimens of really good work foreign influence is distinctly seen In the west the art of France and Flanders, and in the south that of Italy, are predominant Perhaps the finest MS of this southern style to be seen in England is a Psalter belonging to Lord Ashburnham, which was probably executed in the 14th century at Prague, and is full of miniatures which in drawing and colouring follow the Italian school

When we enter the 15th century we find great changes in both the great English and French schools In England the graceful drawing of the previous century has disappeared At first, however, some beautiful examples of purely native work were produced, and still remain to excite our admiration Probably the most perfect of these MSS are the Sherborne Missal belonging to the duke of Northumberland, and a very beautiful volume, a Book of Hours, in the library of Lord Ashburnham The care bestowed upon the modelling of the features is particularly noticeable in English work of this period In decoration the border of the 14th century had by this time grown to a solid frame surrounding the page, but now another form of most effective ornament was also used, consisting of twisted feather like scrolls brightly coloured and gilt As the century advanced native English work died out, and French and then Flemish influence stepped in

In France immense activity was shown all through the 15th century in the illumination and illustration of books of all kinds, sacred and profane, and it is in the MSS. of that country, and, a little later, in those of the Low Countries, that we can most exactly watch the transition from mediæval to modern painting Early in the century there were executed in France some of the most famous MSS which have descended to us In these the colouring is most brilliant, the figure drawing fairly exact, and the landscape begins to develop The border has grown from the branching pendant to a framework of golden sprays or of conventional and realistic leafage and flowers Towards the middle of the century the diaper disappears for ever, and the landscape is a recognized part of the miniature, but perspective is still at fault, and the mystery of the horizon is not solved until the century is well advanced And now Flemish art, which had long lain dormant, sprang into rivalry with its French sister, under the stimulus given to it by the Van Eycks, and the struggle was carried on, but unequally, through the rest of the century French art gradually deteriorates, the miniatures become flat and hard, nor are these defects compensated for by the meretricious practice of heightening the colours by profusely touching them with gold The Flemish artists, on the other hand, went on improving in depth and softness of colouring, and brought miniature painting to rare perfection The borders also which they introduced gave scope for the study of natural objects Flowers, insects, birds, and jewels were painted in detached groups on a solid framework of colour surrounding the page

But if, as the 15th century drew to its close, the Flemings had outstripped their French rivals, they had now more powerful antagonists to contend with The Italians had been advancing with rapid strides towards the glories of the Renaissance Early in the century there arose a taste for older models As, for their writing and afterwards for their printing they went back to the 11th and 12th centuries for their standards, so they adopted again the interlacing designs of the Lombardic school for their ornament and produced beautiful borders of twining patterns relieved by colour, or they took natural objects for their models, and painted borders of delicate flowers made still more brilliant with clustering stars of gold Later, they drew from the ancient classical designs inspiration for the wonderful borders of arabesques, medallions, griffins, human forms, antique objects, &c, which they brought to such perfection early in the next century Their miniatures rose to the rank of exquisitely finished pictures, and were executed by some of the best artists working under the patronage of such great houses as those of Sforza and Medici

Here then having advanced to the threshold of the domain of modern painting, we leave these two great schools of miniaturists in possession of the west of Europe The Flemings had the wider field, they were wanderers from home, and their works are scattered through many lands, from England in the north to Spain in the south But Italian art had greater inherent strength, and will always hold the first rank To instance a few of the more famous MSS of this closing period of miniature painting the Breviary of Isabella the Catholic, in the British Museum, is a masterpiece of Flemish art produced in Spain, the Grimani Breviary at Venice is another fine example of the same school Some beautiful Italian miniatures (executed for Leo X and others) were in the collection lately sold by the duke of Hamilton The earl of Ashburnham possesses a most delicately illuminated Book of Hours written for Lorenzo dei Medici by the famous scribe Simbaldo in 1485, as well as a MS to which Perugino and his contemporaries contributed paintings And in one MS, a Book of Hours belonging to Mr Malcolm of Poltalloch, are gathered some of the best miniatures of both schools, viz, a series of exquisite paintings by Milanese artists supplemented by later ones of the finest Flemish type (E M T)

MINIMS See FRANCIS (ST) OF PAOLA, vol IX p 695

MINING

THE art of mining consists of those processes by which useful minerals are obtained from the earth's crust This definition is wider than what is popularly known as mining for it includes not only underground excavations but also open workings at the same time it excludes underground workings which are simply used for passages, such as railway tunnels and sewers, and galleries for military purposes We must remark also that the word "mine," or its equivalent in other languages, varies in signification in different countries on account of legal enactments or decisions which define it Thus, in France and Belgium the workings for mineral are classified by the law of 1810, according to the nature of the substance wrought, into *mines minières, et carrières* In the United Kingdom, on the contrary, it is the nature of the excavation which decides the question for certain legislative purposes, and the term mine is restricted to workings which are carried on underground by artificial light The consequence is that what is merely an underground stone quarry in France becomes a true mine in England, whilst the open workings for iron ore such as exist in Northamptonshire, would be true mines under the French law It is necessary, therefore in an article on mining, to go beyond the English legal definition of a mine, and include the methods of working minerals in excavations open to daylight as well as in those which are purely subterranean Furthermore as it is customary for the miner to cleanse his ore to a greater or less extent before selling it to the smelter, we shall treat, under the head of mining those processes which are commonly known as the dressing or mechanical preparation of ores, and, finally, a few remarks will be made concerning legislation affecting mines in the United Kingdom, accidents in mines and the production of the useful minerals in various parts of the globe

The subject therefore will be dealt with as follows —

1 Manner in which the useful minerals occur in the earth's crust, viz tabular deposits and masses, faults or dislocations

2 Prospecting, or search for mineral

3. Boring with rods and ropes diamond drill

4. Breaking ground, tools employed blasting by various methods, machine drills, driving levels and sinking shafts

5. Principles of employment of mining labour

6 Means of securing excavations by timber or masonry

7 Exploitation, or the working away of strata or veins

8 Carriage or transport of minerals through underground roads

9 Winding, or raising in the shafts, with the machinery and apparatus required

10 Drainage of mines, adit levels, pumps, pumping engines

11 Ventilation and lighting of mines

12 Means of descending into and ascending from mines

13 Dressing or mechanical preparation of minerals

14 Recent legislation affecting mines in the United Kingdom

15 Accidents in mines

16 Useful minerals produced in various parts of the globe

1 *Manner in which the Useful Minerals Occur* —The repositories of the useful minerals may be classified according to their shape as (A) tabular deposits, and (B) masses

A *Tabular Deposits* —These are deposits which have a more or less flattened or sheet-like form They may be divided, according to their origin, into (1) beds or strata and (2) mineral veins or lodes

(1) *Beds* —Geology teaches us that a large proportion of the rocks met with at the surface of the earth consist of substances arranged in distinct layers, owing to the fact that these rocks have been formed at the bottom of seas, lakes, or rivers by the gradual deposition of sediment, by precipitation from solutions, and by the growth or accumulation of animal and vegetable organisms If any one of these layers consists of a useful mineral, or contains enough to make it valuable, we say that we have a deposit in the form of a bed, stratum, or seam Of course the most important of all bedded or stratified deposits is coal, but, in addition, we have beds of anthracite, lignite, iron ore, especially in the Oolitic rocks, cupriferous shale, lead bearing sandstone, silver bearing sandstone, diamond, gold, and tin bearing gravels, to say nothing of sulphur, rock salt, clays, various kinds of stone, such as limestone and gypsum, oil shale, alum shale, and slate

The characteristic feature of a bed is that it is a member of a series of stratified rocks, the layer above it is called the *roof* of the deposit, and the one below it is the *floor* Its *thickness* is the distance from the roof to the floor at right angles to the planes of stratification, its *dip* is the inclination downwards measured from the horizontal, its *strike* is the direction of a horizontal line drawn in the middle plane

The thickness of beds that are worked varies within very wide limits Whilst the thickness of certain workable beds of coal is only 1 foot, and that of the Mansfeld cupriferous shale only 10 to 20 inches, we find on the other hand one of the beds of lead bearing sandstone at Mechernich no less than 85 feet thick, and beds of slate far exceeding that thickness It must not be supposed, however, that the thickness of a bed necessarily remains uniform Occasionally this is the case over a very large area, but frequently the thickness varies, and the bed may dwindle away gradually, or increase in size, or become divided into two owing to the appearance of a parting of valueless rock Fig 1 shows beds of shale, limestone, iron ore, and sandstone Any one of these beds may be valuable enough to be worked

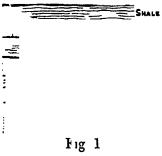


Fig 1

(2) *Mineral Veins or Lodes*—Veins or lodes are tabular or sheet like deposits of mineral which have been formed since the rocks by which they are surrounded, they differ, therefore, by their subsequent origin from beds, which, as just stated, are of contemporaneous origin with the enclosing rocks (although of course cases occur in which the deposit is lying unconformably upon very much older strata, or is covered unconformably by very much younger strata) It is necessary to explain that the term "vein in this definition is used in a more restricted sense than is sometimes customary among miners, who speak of *veins* of coal, clay ironstone and slate, which geologically are true beds They see a band of valuable mineral or rock, and, careless of its origin, call it metaphorically a vein or seam On the other hand, the definition is broader than that which prevails among some geologists, who would confine the term vein to deposits occupying spaces formed by fissures

The term "lode was defined in 1877 by Mr Justice Field in the celebrated Eureka *v* Richmond case as follows —"We are of opinion, therefore, that the term, as used in the Acts of Congress is applicable to any zone or belt of mineralized rock lying within boundaries clearly separating it from the neighbouring rocks This interpretation seems suitable for the peculiar mining tenure of the United States, where the discoverer of a vein or lode can obtain a mining claim of 500 yards in length along the lode It protects the prospector, whose object is to obtain a secure title, the mode of origin of the deposit being a matter of small importance to him so long as it is worth working In many cases also it would be impossible to decide upon the mode of origin until workings had progressed considerably, and even then there would be room for disputes

No doubt a very large number of mineral veins are simply the contents of fissures, others are bands of rock impregnated with ore adjacent to fissures or planes of separation, others, again, have been formed by the more or less complete replacement of the constituents of the original rock by particles of ore

Veins may occur in igneous or in sedimentary rocks, and in the latter they frequently cut across the planes of stratification.

Like a bed, a vein has its dip and strike, but, as the dip of veins is generally great, the inclination is usually measured from the vertical, and is then spoken of as the *underlie* or *hade* The bounding planes of a vein are called the *walls* or *cheeks* and they are frequently smooth and striated, showing that one side must have slid against the other The upper wall is known as the *hanging wall*, the lower one as the *foot wall* The width of a vein is measured at right angles to the walls

A typical example of a fissure vein is shown in fig 2, representing a lead lode in slate at Wheal Mary Ann mine[1] in Cornwall It is evident that a fissure in the surrounding slate has here been filled up by the successive deposition of bands of mineral on both sides

A large proportion of the contents of a lode may consist of fragments of the walls that have fallen into the original fissure, and these are often tightly cemented together by minerals that have been introduced subsequently The horizontal section of part of the Comstock lode[2] (Plate IV) shows much ' country rock enclosed within the walls

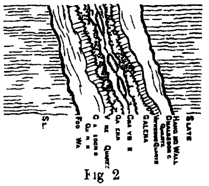


Fig 2

Where a lode consists of rock impregnated with ore, the mineralized part may fade away gradually into the surrounding rock (*country*) without there being any distinct wall, as shown in fig 3, which is an illustration taken from the Great Flat Lode[3] near Redruth in Cornwall

The celebrated Ruby Hill deposit in the Eureka district Nevada, is a mineralized zone of dolomitic limestone varying in width from a few inches to 450 feet, and having a mean width of 250 feet It contains numerous irregular ore bodies, which consist mainly of highly ferruginous carbonate of lead, rich in silver and gold This mineralized limestone band, long called a lode by miners, has been determined by the decision just mentioned to be a lode in the eyes of the law

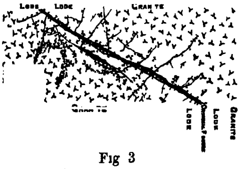


Fig 3

Veins often continue for a great distance along their strike The Van lode in Montgomeryshire is known for a length of 9 miles, whilst the Great Quartz Vein in California has been traced for a distance of no less than 80 miles Veins are of less uniform productiveness than beds and are rarely worth working throughout Rich portions alternate with poor or worthless portions The rich parts have received various names according to the forms they assume fig 4 represents a longitudinal section along the strike (*course*) of a lode and the stippled parts are ore bodies B,B B are *bunches* is a large bunch or *course of ore* when an ore body forms a sort of continuous column we have a *shoot*, and ore bodies which on being excavated leave chimney like openings are called *pipes* (fig 4, C) In the United States the Spanish word *bonanza*, literally meaning fair weather or "prosperity, is frequently used for a rich body of ore

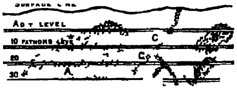


Fig 4

The richness of veins is dependent in many cases upon the nature of the adjacent rock (*country*), upon the underlie, and upon the strike, variations in any one of these three elements being often sufficient to cause a decided change of productiveness

Various theories have been formed concerning the origin of mineral veins Some geologists suppose that the minerals now constituting the veins have been dissolved out of the adjacent rocks and re deposited in the vein cavity, others, on the contrary, believe that the ores have been brought up from great depths by mineral springs In all probability both theories are correct some lodes having been formed by the former process and some by the latter, and, furthermore, other lodes appear to owe their origin to a gradual substitution of valuable minerals in the place of some of the constituents of a worthless rock One of the most important contributions to the science of ore deposits of late years has been the discovery by Professor F Sandberger of small quantities of silver, lead, copper, nickel, cobalt, bismuth, arsenic, antimony, and tin in silicates such as olivine, augite, hornblende, and mica, which are constituents of igneous rocks He therefore regards these rocks as the sources from which lodes have derived their riches

B *Masses*—These are deposits of mineral, often of irregular shapes, which cannot be distinctly recognized as beds or veins Such, for instance, are the red hæmatite deposits of the Ulverston district (fig 5[1]) and the brown hæmatite deposits (*churns*) of the Forest of Dean, which occupy irregular cavities in the Mountain Limestone. These may have been formed by the percolation of water bringing down iron in solution from overlying Triassic rocks Other examples of masses are the calamine deposits of Altenberg[2] (fig 6), Sardinia, and Lombardy, the iron ore deposits in Missouri, such as Iron Mountain and Pilot Knob, the huge upright "necks" or "pipes" of diamantiferous rock in South Africa and the granite decomposed *in situ* worked for china clay in Cornwall

---

[1] C Le Neve Foster, "Remarks on the Lode at Wheal Mary Ann, Menheniot,' *Trans Roy Geol Soc Cornwall*, vol ix p 153

[2] James D Hague, in *United States Geological Exploration of the Fortieth Parallel*, vol iii, "Mining Industry, Washington, 1870, Atlas, plate 11

[3] C Le Neve Foster, "On the Great Flat Lode south of Redruth and Camborne, and on some other Tin Deposits formed by the Alteration of Granite,' *Quart Jour Geol S* vol xxxiv. p. 644

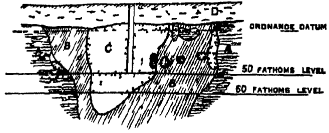


FIG 5 —Vertical Section, Roanhead Mine A, Mountain Limestone, B red hæmatite, C sand and clay, D, gravel Scale $\frac{1}{5000}$

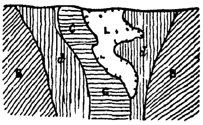


FIG 6 —Vertical Section, Altenberg B, slate *d*, dolomite, C, calamine, L clay

Under this head also are included by most authors the so called "stockworks" or "reticulated masses," names applied to masses of sedimentary or igneous rock which are penetrated by so many little mineral veins as to make the whole worth excavating

It must be understood that we cannot expect nature to make distinct lines of demarcation between the different kinds of deposits Though we may be able to see clearly that a seam of coal is contemporaneous with the enclosing rocks and that a vein intersecting beds of shale and sandstone was formed subsequently, cases frequently occur where the origin of the mineral is uncertain For example we have the lead bearing sandstone of Mechernich and the silver bearing sandstone of Utah The grains of sand are of sedimentary origin but opinions differ as to whether the lead and silver respectively were deposited with the sand or were introduced subsequently by solutions percolating through the beds In the case of the well known bed of Cleveland ironstone, Dr Sorby considers that the iron was derived partly from mechanical deposition and partly from subsequent chemical replacement of the originally deposited carbonate of lime [3] Furthermore a bed may be so folded and contracted as to lose its original sheet like form in places and assume the shape of an irregular mass This may happen even with a coal seam [4]

All kinds of deposits are subject not only to irregularities of origin dependent upon their mode of formation but also to dislocations or shiftings known as faults heaves or throws

We will take the case of a bed (fig 7) AB is a seam which ends off suddenly at B whilst the continuation is found at a lower level at CD The bed was evidently once continuous but a fracture took place along the line XY followed by a displacement As a rule

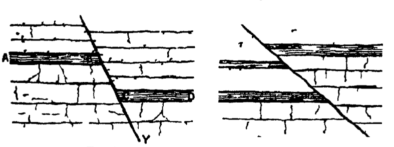


Fig 7

the portion of rock on the hanging wall side of a fault appears to have slid downward but occasionally this is not so and we have a reversed fault fig 8 It is very evident in some cases, that the motion took place not along the line of greatest dip but in a diagonal direction, causing a displacement sideways as well as downwards Nevertheless, where beds or veins are not horizontal, a mere shift along the line of dip is sufficient to cause an apparent heave sideways This will be understood from fig 9 Let AB and CD represent two portions of a lode dislocated by the fault EF The point B' corresponded originally with B, and the dislocation was caused by a simple sliding of B along the line of dip BB' An instance of the complication caused by a succession of faults is shown in fig 10 [5]

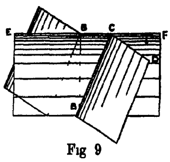


Fig 9

2 *Prospecting, or Search for Mineral* —The object of the prospector is to discover valuable deposits of mineral. This search is beset with many difficulties the outcrops of mineral deposits are frequently hidden by soil, the nature of the deposit itself is generally entirely changed near the surface, and, in addition to this, the explorer may have to pursue his work in trackless forests far away from any settlements

Prospecting.

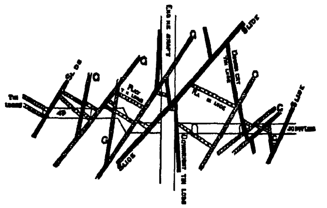


FIG 10 —Vertical Section Penhalls Mine Cornwall G, G, G, small veins called *gossans* in the St Agnes district

The prospector seeks for natural sections of the rocks, such as occur in cliffs or in river valleys and their tributary gullies and gorges, he examines the materials constituting the river beds, often digging up and washing portions in a pan, in order to ascertain whether they contain traces of the heavy ores or metals If, while prospecting in a valley, he discovers stones that have the appearance of having once belonged to veins, he endeavours to trace them to their source, and is perhaps rewarded by finding similar fragments, but less water worn, as he goes up the stream, further on he may come upon large blocks of veinstuff lying about, and finally find the vein itself laid bare in a gorge, or at the bottom of a brook, or possibly projecting above the soil in the form of huge crags of quartz Thus at the Great Western quicksilver mine in California the outcrop of the vein appears as a dike over 100 feet wide, and having precipitous sides in places 75 feet high [6] Loose pieces of veinstuff found lying about are known in Cornwall as shoad stones, and *shoading* is the term given to the process of tracking them to the parent lode

The upper portion of a deposit is frequently much altered by atmospheric agencies, and bears little resemblance to the undecomposed bed or vein which will eventually be met with at a greater or lesser depth The principal difference consists in the change of sulphides into oxides or oxidized compounds Thus iron pyrites, which is such a common constituent of mineral veins, is converted into hydrated oxide of iron, and a vein originally consisting largely of iron pyrites and quartz now becomes a cindery mixture of quartz and ochre, known in Cornwall as *gossan* This gossan, or *iron hat*, may often furnish important indications concerning the nature of the lode itself, because such minerals as pyromorphite or cerussite point to the existence of galena, whilst melaconite, cuprite, malachite, and azurite are the forerunners of chalcopyrite or copper glance The gossan itself may contain a sufficient quantity of valuable ores to be worth working

The seams containing native sulphur in Sicily often show no trace of that element immediately at the surface, as the sulphur bearing limestone weathers into a soft white granular or pulverulent variety of gypsum, called *briscale* by the miners, and considered by them as affording important indications concerning the bed itself[1]

---

[1] Fr Moritz Wolff Beschreibung der Rotheisenerzlagerstatten von West Cumberland und North Lancashire, *Stahl und Eisen* 2 Jahrgang N 12 plate vi

[2] M Braun *Zeitschr d d geol Gesellsch* 1857, vol ix and A von Groddeck *Die Lehre von den Lagerstatten der Erze*, Leipsic, 1879, p 242

[3] *Quart Jour Geol Soc*, vol xxxv (1879) p 85, Anniversary Address of the President

[4] J Callon *Lectures on Mining*, vol i p 63, and Atlas, plate viii. fig 44

[5] J W Pike, "On some remarkable *heaves* or *throws* in Penhalls Mine, *Quart Jour Geol Soc*, vol xxii p 537

[6] Luther Wagoner, "The Geology of the Quicksilver Mines of California, *Engineering and Mining Journal*, vol xxxiv p 334

Other signs of mineral deposits are given by springs and by certain plants dependent upon the deposit or its associated minerals for part of their nourishment The appearance of the so called lode lights may be explained by the production of phosphoretted hydrogen from the action of organic matter and water upon phosphates, which are so common in the upper parts of mineral veins and one hears also of differences in the appearance of the vegetation along the line of the deposit of places where snow will not lie in winter, and of vapours hanging over the ground Though some writers refuse to put any value upon these indications they should not be entirely overlooked, because the outcrop of a lode of different nature and texture to the surrounding rocks and which is generally a channel for water may readily cause the phenomena just mentioned Where the surface is cultivated and the natural springs are tapped by adit levels or other mine workings these appearances cannot be looked for to any great extent With one special mineral magnetic iron the position of the deposit may be traced out with some degree of accuracy with a dipping needle this is used in Sweden

After having acquired an idea of the position of a vein or seam by some of the surface indications just mentioned, it is necessary, before attacking it by shafts or levels, to obtain more certain data concerning it In the case of mineral veins, trenches are dug at right angles to the supposed strike and, when the upper part of the deposit has been cut in several places, its general course and dip can be determined sufficiently for the purpose of arranging the future workings These trenches are called "costean pits in some cases, instead of a trench, a pit is sunk a short distance and a little tunnel driven out

Where the mineral to be wrought occurs as a bed or mass, the process of boring is resorted to, and indeed this method is also applied in the case of veins, especially in the United States Boring is a work of such importance that it deserves to be treated under a separate heading

Boring.

3 *Boring with Rods and Ropes—Diamond Drills* —The object of boring is to reach a deposit by a small hole and ascertain its nature, its depth from the surface, thickness, dip, and strike Bore holes are also used for obtaining water, brine and petroleum, which either rise to the surface or have to be pumped up from a certain depth, and finally for tapping water in old workings or for effecting ventilation The methods of boring may be classified as follows —(1) boring with the rod, (2) boring with the rope, (3) boring with the diamond drill

Boring with rods

In the first method tools for cutting and removing the rock are fixed to rods, which are lengthened as the hole increases in depth, and which are worked by hand or by machinery at the surface Where the ground is soft such as sand or clay tools like augers can be employed but in harder ground it becomes necessary to have recourse to percussion various forms of chisel are used the simplest being made of the shape shown in fig 11 The rods generally consist of bars of square iron, from 1 inch to 2 inches on the side The length of each rod depends upon the height of the tower, derrick, or shears erected above the bore hole, which should be an exact multiple of the individual parts These are made in lengths of 15 to 30 or rarely 40 feet, and with a suitable tower it is possible to detach or attach two or three lengths at a time, instead of having to make or unmake every joint The mode of connexion usually preferred is by a screw joint as shown in fig 12, care is taken to have all the joints exactly alike, so that any two bars can be screwed together In order to diminish the weight of the rods, which becomes considerable in deep holes, wood has sometimes been employed The rods are connected by male and female screws attached to the rods by sockets of sheet iron, or by a fork like arrangement At the surface a head is screwed to the uppermost rod by which the rods can be lifted, and they are turned by means of cross bars called tillers

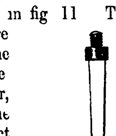
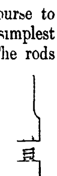



Fig 11 —Chisels Fig 12

When the depth is small the rods are lifted by hand and then allowed to drop, being turned slightly at each lift so that the cutting chisel may strike a new place each time For greater depths a lever has to be employed the rods being suspended at one end whilst the other end can be pressed down by men using their hands or feet The spring pole is another arrangement, in which the elasticity of a long pole is made use of for lifting the rod at each stroke The length of the stroke can be maintained the same while the bore hole is deepened by means of a screw in a swivel head at the top of the rod

With deep holes, and especially those of large diameter steam machinery has to be employed for working the rod the engine may be direct acting and stand immediately above the bore hole but a commoner arrangement is to employ a single acting cylinder working a beam Occasionally also the beam is actuated by a connecting rod worked by a crank

The actual boring machinery has now been described, and the mere boring appears to be a very simple matter consisting only in lifting the rod a little and allowing it to drop the rod being turned slightly before each stroke Nevertheless the process of putting down a bore hole is not so simple as it seems for there are numerous indispensable accessory operations which take up much time In the first place the debris have to be removed and in order to effect this the rods must be drawn up the swivel head is disconnected and a cap screwed on A length of rods is now drawn up by a hand or steam windlass and disconnected It is well to have as many caps as there are lengths to be drawn up and then each length can be suspended in the house Sometimes a *grip* which catches the rod at the bulging joint is used instead of a cap The next operation consists in lowering by means of a rope the *shell pump* or *sludger* which is a hollow cylinder with a clack or a ball valve (fig 13) It is worked up and down a little till it is filled and it is then drawn up and emptied at the surface The operation is repeated if necessary and the boring is resumed with the rod

Fig 13

Occasionally a bore hole has to be widened slightly with a tool called a *reamer* Soft beds may have to be bored through with a *wimble* and unless the rocks are hard and firm the hole has to be lined with a tube generally of sheet iron Accidents may occur causing an immense amount of trouble such as the breaking of rods or chisel and many ingenious implements have been devised for seizing the broken rod or the fragments of tools which prevent further progress with the work

In boring at considerable depths the weight of the rod becomes so great that much vibration ensues when the mass is suddenly arrested by the chisel striking against the bottom of the hole Various devices have been contrived for overcoming this difficulty and producing a tool which will act independently of the rod One of the best known arrangements is the free falling tool invented by Kind (fig 14)[3] The head of the actual boring rod is held by a click or grapple when the main rod descends the resistance of the water in the hole slightly stops the sliding disk D the jaws J J open the head is disengaged and the boring part falls and strikes the bottom without any injurious vibrations being communicated to the main rod When the head descends farther the head is caught again by the click Special tools also are used for cutting an annular groove at the bottom of a bore hole and breaking off the core which is then brought up with certain precautions so as to show the nature and dip of the strata traversed

In order to obviate the great loss of time which ensues from connecting and disconnecting long lengths of rods, recourse may be had to boring with the rope In this method, known as the Chinese method, the chisel is worked by a rope in the same manner as the sludger already described Messrs Mather and Platt of Manchester have long used with success, in many parts of England and various other countries, a system of boring by means of a flat hempen rope

Fig 14

The most important modification of late years in the

---

[1] Lorenzo Parodi, *Sull Estrazione dello Solfo in Sicilia*, 1873, pp 7 and 24

[2] Serlo *Leitfaden zur Bergbaukunde*, Berlin, 1878 i 79

[3] J Callon, *Lectures on Mining* vol i, Atlas, plate ix fig 52.

Diamond drill process of making bore holes is the introduction of the diamond drill The working part of the drill consists of the so called crown which is a short piece of tube made of cast steel, at one end of which a number of black diamonds are fastened into small cavities (fig 15) The crown is screwed on to wrought iron pipes which constitute the boring rod Machinery at the surface causes the rod to rotate, and the result is the cutting of an annular groove at the bottom of the hole, leaving a core, which, breaking off from time to time, is caught by a little shoulder and brought up to the surface with the rod In places where it is not necessary to make any verification of the rocks traversed, the crown is arranged with diamonds in the centre also The debris, in either case, are washed away by a stream of water, which is forced down the tube and flows up the sides of the hole With this system a bore hole can be deepened continuously at a speed altogether unattainable by the other methods, which require stoppages for cleaning out It has the further advantage of making it possible to drill holes in any direction, and prospecting diamond drills are constantly used with much success inside many metal mines, especially in the United States

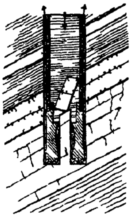


Fig 15 —Diamond Drill

Fig 16[1] shows the Little Champion Rock Drill which is largely employed in the Lake Superior district for prospecting It can be used above or below ground Two inclined cylinders drive a horizontal crank shaft which works bevel gear causing the drill to revolve At the same time a countershaft is likewise set in motion and this effects the advance of the drill by gearing driving the feed screw as there are three kinds of gearing the speed can be varied at pleasure The feed screw and its connexions are carried by a swivel head and this can be turned so as to drill holes at an angle The drum shown above the cylinders is used for hoisting out the drill rods by a rope The rods are lap welded iron tubes 1⅝ inches in diameter fitted with a bayonet joint

Another light portable prospecting drill for underground work is represented in fig 17[2] It is intended for drilling holes 1¼ inches in diameter to a depth of 150 feet The cores which it yields are ⅞ inch in diameter It has double oscillating cylinders 3½ inches in diameter with 3½ inches stroke which are run up to a speed of 800 revolutions The drill can be set to bore in any direction by turning the swivel head on which it is carried

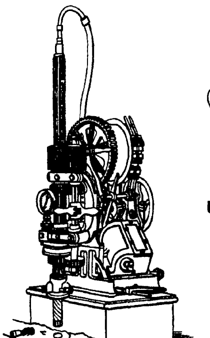


Fig 16 —Little Champion Rock Drill

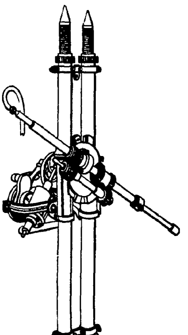


Fig 17

The larger rock drill used by the American Diamond Rock Boring Company for putting down holes to a depth of 2000 feet consists of a 20 horse power boiler with two oscillating 6 inch cylinders and the necessary gearing for working the drill all mounted upon a carriage, so that the whole machine is readily moved from place to place The feed is effected by gearing or by hydraulic pressure a 2⅜ inch crown is employed leaving a 2 inch core Each separate drill rod is 10 feet long The total weight of the machine is about 4 tons

4 *Breaking Ground—Tools Employed—Blasting by Various Methods—Machine Drills—Driving Levels and Sinking Shafts* —The kind of ground in which mining excavations have to be carried on varies within the widest limits, from loose quicksands to rocks which are so hard that the best steel tools will scarcely touch them

Tools. Loose ground can be removed with the shovel but in the special case of peat sharp spades are employed, which cut through the fibres and furnish lumps or sods of convenient form for drying and subsequent use as fuel What is called *fair*, *soft*, or easy ground, such as clay, shale, decomposed clay slate, and chalk, requires the use of the pick and the shovel The pick is a tool of very variable form, according to the material operated on Thus there are the navvy s pick, the single pointed pick with a striking head at the other end called the poll pick (fig 18), and numerous varieties of the double pointed pick (fig 19), the special tool of the collier, but also largely used in metal mining When the ground, though harder, is nevertheless "jointy,' or traversed by many natural fissures, the wedge comes into play The Cornish tool known as a *gad* is a pointed wedge (fig 20) The so-called ' pick and gad work consists in breaking away the easy ground with the point of the pick, wedging off pieces with the gad driven in by a sledge or the poll of the pick, or prizing them off with the pick after they have been loosened by the gad The Saxon gad is held on a little handle, and is struck with a hammer It is used for wedging off pieces of jointy ground, and in former days even hard rocks were excavated by its aid The process consisted in chipping out a series of parallel grooves and then chipping away the ridges left between the grooves As a method of working this process is obsolete, but it is useful on a small scale for cutting recesses (*hitches*) for timber, for dressing the sides of levels or shafts before putting in dams, and for doing work in places where blasting might injure pumps or other machinery

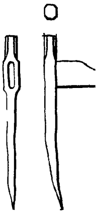


Fig 18 Poll pick

Fig 19 —Double pointed Pick

Fig 20 —Gad

We now come to hard ground and in this class we have a large proportion of the rocks met with by the miner, such as slate of various kinds, hard grits and sandstone, limestone, the metamorphic schists, granite, and the contents of many mineral veins Rocks of this kind are attacked by boring and blasting The tools employed are the jumper, the borer or drill, the hammer, the sledge (*mallet*, Cornwall), the scraper and charger, the tamping bar or stemmer, in some places the pricker or needle, the claying bar, the crowbar, and finally the shovel for clearing away the broken rock

The jumper (fig 21) is merely a long bar of iron terminating in two chisel like edges made of steel, generally there is a swelling in the middle, and sometimes the jumper tapers all the way from the middle to the edge or bit The jumper is most commonly used when it is necessary to bore holes downwards, and is

Fig 21.

---

[1] *Engineering and Mining Jour*, vol xxxiii p 119

[2] *Ibid*, vol. xxxiii p 273

largely employed in quarries, occasionally it is used in boring holes horizontally, as for instance in the salt mines of Cheshire The jumper is held in the desired direction, lifted up, and thrust down, it is turned a little after each stroke

However, the miner's tool is generally the borer proper, or drill (fig 22), which is a bar of round or octagonal steel, usually from ⅞ inch to 1½ inches in diameter, with one end forged into a chisel shaped edge, the exact shape and degree of sharpness varying according to the hardness of the rock The hole is bored by striking the drill with a hammer or sledge and turning it after each blow Boring is said to be single handed if the miner holds the drill in one hand and strikes with the hammer in the other, whilst it is called double handed when one man turns and another strikes The hammers for single handed boring usually vary in weight from 2 to 6 or 7 ℔ The double handed boring hammer, or sledge (fig 23), weighs from 6 to 10 ℔ or more If a hole is directed downwards, the miner pours in a little water and bores the hole wet From time to time he draws out the sludge with the scraper, a little disk at the end of a metal rod, and he takes a fresh borer when the tool he is using has become blunt The depth bored varies with the rock and the nature of the excavation, but in driving levels in the ordinary way the depth is commonly from 18 inches to 3 feet

Fig 22

Fig 23 —Sledge Hammer

Holes for blasting are sometimes bored by tools like carpenters' augers One of the simplest, which is used in some French slate mines, is very like a brace and bit, and the tool is kept pressed against the rock by means of a screw fixed in a frame resting on the ground

The pricker, or needle, is a slender tapering rod of copper or bronze, with a ring at the large end It is used for maintaining a hole in the *tamping* through which the charge can be fired The use of needles made of iron is prohibited in many countries, on account of the danger of their striking sparks which might fire the charge The tamping bar, or *stemmer*, is a rod of iron, copper, or bronze, or iron shod with copper, and it is used for ramming in dried clay, slate pounded up, or other fine material, upon the powder, and so creating a resistance sufficient to make the gases generated by the explosion of the charge rend the rock in the manner required The claying bar is used for lining wet holes with clay, and so rendering them temporarily watertight

Shovels vary much in different districts In the south west of England the long handled shovel is preferred to the common one with a short handle, in Germany the ore or rubbish is frequently scraped into a tray with a sort of hoe

Explosives In addition to these tools the miner requires an explosive, and a means of firing the charge at the bottom of the hole which will give him time to escape Twenty years ago gunpowder was the only explosive in common use in mines, but at the present day its place has been taken to a very large extent by mixtures containing nitro glycerin or gun cotton The powder used for blasting in mines usually contains less saltpetre than that which is employed for sporting or military purposes The following is an analysis of mining powder by Captain Noble and Sir F Abel [1]—

Saltpetre	61 66	Oxygen	2 23
Potassium sulphate	0 12	[illegible]	0 59
,, chloride	0 14	Water	1 61
Sulphur	15 06		
Carbon	17 93		100 00
Hydrogen	0 66		

Gunpowder compressed into cylinders of diameters suitable for bore holes, and provided with a central hole for the insertion of the fuse, has lately been brought forward with some success

Nitro glycerin or glyceryl nitrate is a light-yellow oily liquid which is very sensitive to shocks, under the action of a fulminating cap it explodes with great violence Its chemical composition is expressed by the formula $C_3H_5(NO_2)_3O_3$ or $(C_3H_5)3NO_3$, its specific gravity is 1 6 It has been found so dangerous that its use by itself has been given up, but on the other hand the mixture of nitro glycerin and infusorial earth (*Kieselguhr*) called dynamite or giant powder is now one of the commonest explosives met with It has the advantage over powder that it is far more powerful, that it may be used in wet holes or under water, that it is very effective even in ground full of "vughs or cavities, and that it requires no hard tamping, which is always a source of danger Its plasticity too enables it to fill the space at the bottom of a bore hole, which is rarely a true cylinder, more completely than any solid cartridge can do One disadvantage is that it has to be thawed in cold weather, and there is also the fact that occasionally the whole of a charge of dynamite fails to go off, and unnoticed remnants have exploded and caused serious and even fatal accidents when struck with the pick or borer The danger is enhanced when the remnants have been left in contact with water, which causes a separation of the sensitive nitro glycerin, so that even a blow upon the adjacent rock may lead to an accident if any of the explosive oil has leaked into cracks The strongest dynamite contains about 75 per cent of nitro-glycerin, the rest being kieselguhr A newer explosive is blasting gelatin, it is made by mixing nitro cotton with nitro glycerin, until enough nitro-cotton has been dissolved to convert the nitro glycerin into a jelly like mass The blasting gelatin in ordinary use contains no less than 93 per cent of nitro-glycerin, with 7 per cent of nitro-cotton, and its strength is very great

Gun-cotton *per se* is not much in favour in ordinary mining, but mixed with some nitrate or mixture of nitrates, such as the nitrates of barium and potassium, and known as cotton powder, tonite, and potentite, it is employed extensively Though not quite so powerful as dynamite, nitrated gun cotton possesses the important advantage of not requiring to be thawed in cold weather As in the case of dynamite, accidents have been caused by remnants of charges, and with both explosives it is necessary to examine carefully the bottoms of all holes after blasting, and to destroy any possible remnants by firing off a detonator in any bottom or "socket which cannot with certainty be pronounced free from danger

Safety fuse The commonest method of firing a charge is by means of the *safety fuse*, a cord containing a core of gunpowder introduced during the process of manufacture, it may be rendered waterproof by tar or gutta percha

In blasting in the ordinary way the charge of gunpowder is put in either loose or enclosed in a paper bag and it is pressed down to the bottom of the hole with a wooden stick, whilst a piece of fuse also is inserted extending from the charge well beyond the hole If the powder is loose the miner carefully wipes down the sides of the hole with a wet *swab stick* (a wooden rod with the fibres frayed at one end), or with a wisp of hay twisted round the scraper in order to remove any loose grains adhering to the fuse or the sides of the hole, and then presses in a wad of hay or paper A little fine tamping often the dust from boring a dry hole is now thrown in and rammed down with the wooden charging stick and the same process is repeated, and when harder tamping is required the metal bar is brought into operation, until the hole is completely filled

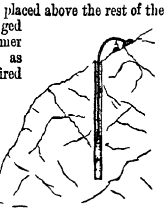
As the safety fuse burns slowly, at the rate of about 2 or 3 feet a minute, the miner can secure ample time for retreat by taking a sufficient length It is usual to ignite the fuse by a candle end fixed under it by a piece of clay, and it takes a little time for the candle to burn through the fuse

The old plan of firing a charge which is still in use in many places, *consists in inserting* the needle into the charge and then tamping up the hole Care is taken to draw out the needle a little as the tamping proceeds so as to prevent too much force being required for its final withdrawal The small hole left in this way serves for the insertion of a straw, rush, or series of small quills, filled with fine powder which like the fuse reaches from the charge to the outside A short squib which shoots a stream of sparks down the needle hole is also used occasionally The straw or squib is lighted by some kind of slow match, made either by dipping a cotton strand in melted sulphur or soaking a piece of paper or a lucifer in the tallow of a candle, touch paper also is used

---

[1] "On Fired Gunpowder, *Phil Trans*, 1880, p 225

Dynamite, blasting gelatin, gun cotton, and cotton powder are fired by the detonation of a fulminating cap A long copper cap containing fulminate of mercury is fastened into the safety fuse by squeezing with a pair of nippers, and is then inserted into a small cartridge of the explosive (*primer*), and placed above the rest of the charge Fig 24 shows a hole charged with two dynamite cartridges, a primer with cap, and filled up with water as tamping Sometimes gun cotton is fired by a small charge of powder above it



24

Several substitutes for explosives have been tried with the object of getting rid of the flame, which is dangerous in collieries giving off fire damp Among these may be mentioned plugs of dry wood which swell when wetted wedges worked by hydraulic pressure, cartridges containing compressed air at extremely high pressures, and lastly cartridges of compressed lime which expands when water is brought into it

For the purpose of firing several holes simultaneously, Messrs Bickford, Smith, & Co, the original inventors and makers of the safety fuse, have brought out a new fuse (fig 25), the action of which will be easily understood from the figure An ordinary fuse is fixed into metal case called the igniter from which a number of instantaneous fuses convey fire to as many separate holes It is found in practice that this fuse answers very well.

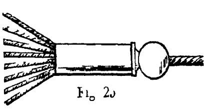


Fig 25

Blasting by electricity Charges may be readily fired singly or simultaneously with the aid of electricity, either of high tension obtained from a frictional, magneto electric, or dynamo electric machine, or of low tension from a galvanic battery The former is preferred

Fig 26 shows a section of one of Brain s high tension fuses A is a cylindrical wooden case containing a paper cartridge B, with an electric igniting composition C at the bottom Two copper wires D D enclosed in gutta percha E E reach down to the composition, where they are about $\frac{1}{50}$ inch apart A copper cap or detonator G is fixed on to the small end of the wooden case The insulated wires D D are long enough to reach beyond the bore hole The ends of the wires are scraped bare, and one wire of the first hole is twisted together with a wire of the next hole, and so on and finally the two odd wires of the first and last hole are connected to the two wires of a single cable or to two separate cables, extending to some place of safety to which the men can retreat Here the two cable wires are connected by binding screws to a frictional electrical machine or dynamo exploder A few turns of the handle charge a condenser, and by pressing a knob or by some other device the circuit is completed and the discharge effected The electricity passes through the fuse wires making a spark at each break and so firing the electric igniting composition The flame flashes through the hole H, and ignites the fulminating mercury I, the detonation of which causes the explosion of the dynamite, blasting gelatin, or tonite surrounding the cap

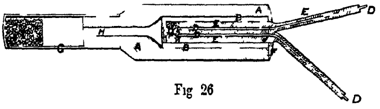


Fig 26

One great advantage of electric firing is that the miner can retire to a perfectly safe place before attempting to explode the charge This is important in sinking shafts, where the means of escape are less easy than in levels. A second advantage is that there is no danger of a "hang fire," an occasional source of accidents with the ordin safety fuse.

Machine drills One of the greatest improvements in the art of mining during the last few years has been the introduction of machinery for boring holes for blasting, most of the machines imitate percussive boring by hand, but a few rotary machines are also in use A percussive drill or perforator consists of a cylinder with a piston to which the drill is fastened Compressed air is made to act alternately on each side of the piston, and in this manner the drill receives its reciprocating motion Various arrangements have been adopted for securing the automatic rotation of the drill In some cases also the advance forward of the machine, as the hole is deepened, is also effected automatically, but in many of the best drills this work is left to the man in charge It is impossible within the limits of this article to describe the various drills now in use, or even to make a complete enumeration of them.

The following, in alphabetical order, are the names of some of the best known drills —Barrow, Beaumont, Burleigh, Champion, Cornish, Cranston, Darlington, Desideratum, Dœring Dubois and François, Dynamic, Eclipse, Excelsior, Ferroux, Frohlich, Ingersoll, Laxey, Mackean, Osterkampf, Rand, Roanhead, Sandycroft, Schram An account of two of the simplest the Barrow and the Darlington drills, will be sufficient to give a general idea of the construction of these machines

Barrow drill. "The Barrow drill (fig 27) consists essentially of a gun metal cylinder C about 2 feet in length and 4 inches in diameter, in which works a cast steel piston-rod D, fitted with two pistons G, about 12 inches apart, mid way between which is the tappet, or boss, G In a valve box on the top of the cylinder is placed the oscillating slide valve H (shown separately), hinged at M, which is worked by the reciprocation of the tappet G coming in contact with its lower edges, which for this purpose are formed with two slopes at each end, as shown It has ports corresponding with openings in the slide valve face for admitting the fresh steam or compressed air from the inlet pipe I (fig 28) to the ports j at each end of the cylinder, and for letting the spent or exhaust air or steam escape by the exhaust pipe J This simple arrangement constitutes the whole valve gear of the machine.

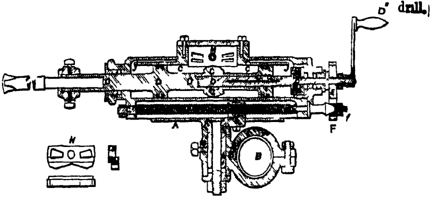


Fig 27

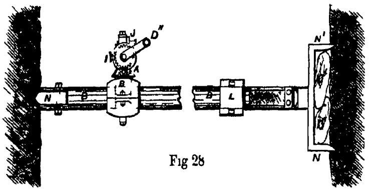


Fig 28

"The borer is inserted into a hole formed in the fore end of the piston rod, and is fixed therein by means of a screw Its rotation is effected by hand, by means of the handle D, turning a spindle D', which is so fitted by means of the cotter *d*, made fast in the piston DG, and fitting in a slot in the spindle D, that the latter can slide in the piston DG, but when turned by the handle causes the piston to turn with it The spindle D has a pinion E gearing into the pinion F, on the adjusting and feeding screw C', so that when the piston D is turned by means of the handle D'' the cylinder C is simultaneously pushed along the bed plate A These pinions can be easily disconnected by loosening the nut *f*, and thus the piston and the adjusting screw can be turned independently of one another when required

"The borers used are respectively 1¼ inches, 1⅛ inches, and 1 inch in diameter, the length of the stroke 4 inches, and the maximum number of blows about three hundred per minute. The air is brought down about 400 fathoms from surface, at a pressure of 50 to 55 lb to the square inch, in wrought iron pipes 2 inches in diameter in the shaft, and 1½ inches in the level, and admitted through a flexible tube into the inlet I on the left hand side of the cylinder The cost of the pipes is rather under 7d a foot, or about 3s 3d per fathom The air is compressed at the surface by a 14 inch compressor, worked by a 12 inch horizontal engine, capable, however, of working two machine drills The gross weight of the machine, including the bed plate and gudgeon, is about 115 lb '

The method of fixing the machine for work is as follows —"The bed plate A of the machine is formed with a gudgeon A which fits into, and can be adjusted to any position in, a socket formed in or on a clamp B which can be fixed on any part of the wrought iron bar or column B, thus forming a universal joint This bar or column can be placed in position either horizontally or vertically, as may be most convenient, but is generally placed across the level against the sides of which it is secured by means of the clamp L, and adjusting screw M and claws N and N If necessary wooden wedges O, O are driven in between the claws and the wall to make it still firmer The weight of the bar is about 120 lb "[1]

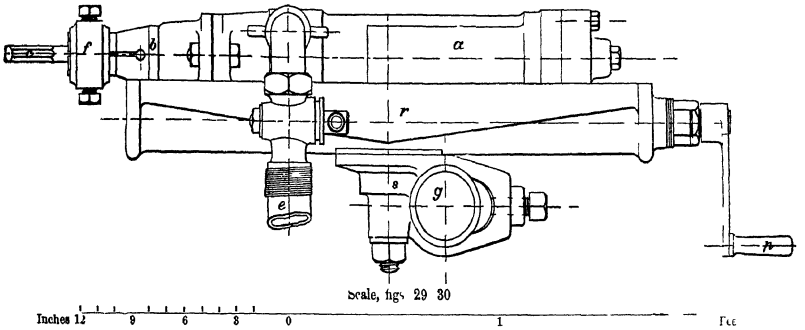


FIG 29 —Side Elevation of Darlington s Rock Drill —Scale $\frac{1}{14}$

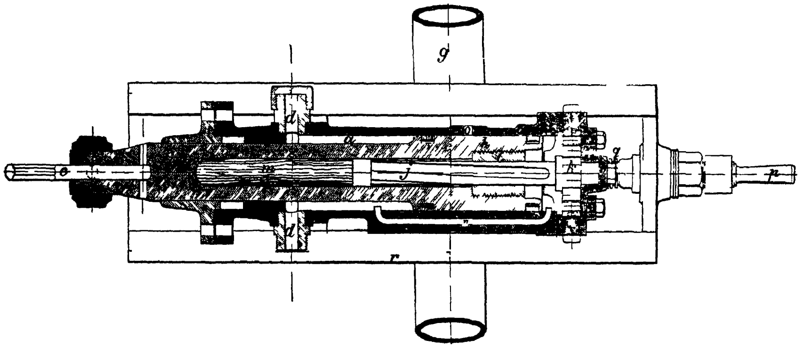


FIG 30 —Horizontal Section of Darlington s Rock Drill —Scale $\frac{1}{14}$

Air-compressing plant of greater size has now been erected at Dolcoath mine, to which the above description refers At Snail beach mine in Shropshire they have two air compressors of 18 inches diameter and 5 feet stroke, the air-main is at first 9 inches in diameter, then 6 inches, whilst 2 inch gas pipe is used in the levels

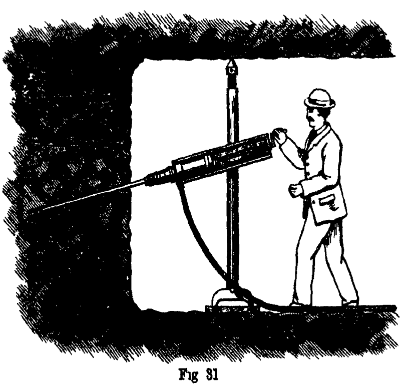


Fig 31

Darlington drill

A rock drill which has done, and is doing, excellent work is that of Mr John Darlington Its construction will be understood by referring to figs 29, 30, and 31 *a* is the cylinder *b* the piston rod, *c* the borer *d*, *d* are two openings for bringing in compressed air, either of which may be used according to the position of the drill, *e* is the inlet hose with a stopcock, *f* drill holder *g* stretcher bar, *h* piston, *j* rifled bar for turning piston and drill *k* ratchet wheel attached to rifled bar *l* rifled nut fixed in the piston head *m* wood for lessening weight of piston rod and blocking up a *n* portway for allowing the compressed air to pass to the top of the piston and give the blow, *o* exhaust portway The action of the drill is as follows The compressed air is always acting on the under side of the piston, and when the upper side of the piston communicates with the outer atmosphere the piston moves rapidly backwards and uncovers the portway *n* The compressed air rushes through and presses against the upper side of the piston, which has a greater area than the lower side, the difference being equal to the area of the piston rod The piston is driven rapidly downwards and the drill strikes its blow At the same time it uncovers the exhaust port and then the constant pressure on the annular area on the underside of the piston produces the return stroke The number of blows per minute is from six hundred to eight hundred The rotation of the drill is effected by the rifled bar On the down stroke of the piston the bar with its ratchet wheel is free to turn under a couple of pawls, and consequently the piston moves straight whilst the bar and ratchet wheel turn When the up stroke is being made the ratchet wheel is held by the pawls and the piston is forced to make part of a revolution As the hole is deepened the cylinder is advanced forwards by turning the handle *p*, this works an endless screw *q* passing through a nut attached to the cylinder *r* is the cradle carrying the feed screw and supporting the cylinder It is centred on the clamp *s* As this clamp can be fixed in any position on the bar, and as the cradle can be turned on the clamp it is evident that holes can be bored in any direction

---

[1] *Proc Mining Institute of Cornwall*, vol i, 1877, p 12

In driving a level with the Darlington drill it is usual to fix the stretcher bar horizontally across the level so as to command the upper part of the face holes can then be bored with the cradle above the bar or below it The bar is then shifted low enough to bore the bottom holes It is found that all the necessary holes can be bored from two positions of the bar The bar therefore has simply to be fixed twice, the alterations in position for boring holes in various directions are managed by shifting the clamp on the bar and turning the cradle on the clamp Fig 31 shows the stretcher bar fixed in a vertical position which is sometimes convenient

In order to clear out the sludge from holes that are "looking downwards a jet of water supplied from a hose attached to a half inch gas pipe leading from a cistern at a higher level, is made to play into the holes during the process of boring

For sinking shafts Mr Darlington has the drill fixed in a cylindrical case with a large external thread which works in a nut on the clamp The drill is fed forwards by turning a hand wheel attached to the case

Rotating drills

Rotating machine drills are also used in mines as well as those with percussive action Stapff pointed out some years ago that, if a rock may be chipped off by power communicated by a blow, it may also be chipped off by a similar amount of power communicated by pressure Brandt's rotatory boring machine consists of a hollow borer which has a steel crown with cutting edges screwed on The tool is kept tight against the rock by the pressure of a column of water, and is at the same time made to rotate by two little water pressure engines, whilst a stream of water passing down through the borer washes away the debris and keeps the cutting edges cool In principle, therefore, this drill resembles the original diamond boring machine of De la Roche Tolay and Perret, save that the crown is made of steel and not of diamonds During the last few years it has been tried with success in railway tunnels and in mines Jarolimek's drill[1] acts also by rotation but the borer is fed forwards and pressed against the rock by a differential screw arrangement The machine can be worked by hand, or by a little water pressure or compressed air engine or an electro motor In working certain minerals occurring in seams the undercutting may be performed by machines similar to those used in coal mines (see vol vi p 68)

We now come to the application of the tools and machine drills to the purpose of breaking ground for driving levels and sinking shafts

Driving levels

A level or drift is a more or less horizontal passage or tunnel, whilst a shaft is a pit either vertical or inclined In driving a level by hand labour in hard ground, the first thing the miner has to do is to take out a cut, *i e*, blast out a preliminary opening in the "end or "forebreast The position of this cut is determined by the joints, which the miner studies carefully so as to obtain the greatest advantage from these natural planes of division Thus fig 32 shows a case in which, owing to joints, it was advisable to begin with a hole No 1, and then bore and blast 2, 3, and 4 one after the other The miner as a rule does not plan the position of any hole until the previous one has done its work, in fact he regulates the position and depth of each hole by the particular circumstances of the case Though a vein and its walls may be hard, there is occasionally a soft layer of clay (DD, DD, fig 33) along one wall (*dig*, Cornwall, *gouge*, United States) The miner then works this away with the pick, and, having excavated a groove as deep as possible, he can now blast down the lode by side holes and so push the level forward

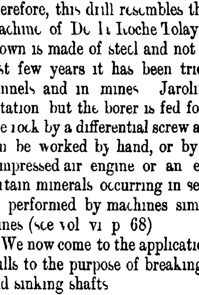


Fig 32

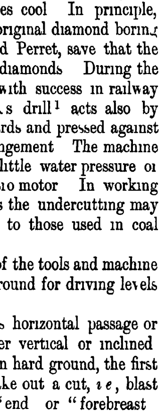


Fig 33

Sinking shafts

In sinking a shaft a similar method of proceeding is observed A little pit (*sink*) is blasted out in the most convenient part, and the excavation is widened to the full size by a succession of blasts, each hole being planned according to circumstances This series of operations is repeated, and the shaft is thus gradually deepened.

Where boring machinery is employed, less attention, and sometimes no attention, is paid to natural joints, because when once the drill is in its place it is very little trouble to bore a few more holes, and the work can then be carried on according to a system which is certain of effecting the desired result

Driving level with machine drills

A common method of procedure for hard ground is shown in figs 34 and 35 Four centre holes are bored about a foot apart at first, but converging till at a depth of 3 feet they are within 6 inches, or less, of each other Other holes are then bored around them until the end is pierced by twenty or thirty holes in all The four centre holes are then charged and fired simultaneously, either by electricity or by Bickford's instantaneous fuse, and the result is the removal of a large core of rock The holes round the opening are then charged and fired, generally in volleys of several holes at a time, and the level is thus carried forward for a distance of 3 feet If the ground is more favourable fewer holes are required, and they may be bored deeper,—in fact as much as 6 feet in some instances Occasionally the four centre holes are directed so that they meet at the apex of an acute pyramid, and then, after all have been charged with blasting gelatin, only one of them receives a primer and cap, the shock of the explosion of one charge fires the other three adjacent charges simultaneously The preliminary opening is not necessarily made in the centre of a level, and sometimes it is blasted out in the bottom or one side

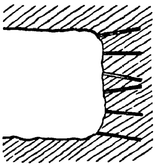


Fig 34

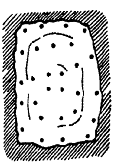


Fig 35

Sinking shafts with machine drills.

In sinking shafts by boring machinery operations are conducted much in the same way as in levels, save of course that the holes are directed downwards Figs 36 and 37 are a section and plan of a shaft which is now being sunk at the Foxdale mines in the Isle of Man About forty five holes are bored in the bottom of the shaft before the drills are removed two of the holes A, B, and occasionally four, are bored only 4 feet deep, and are blasted with ordinary fuse They serve simply to smash up and weaken the core, then the six holes nearest the centre, which are 8 feet deep, are blasted all together with Bickford's instantaneous fuse, and the result is the removal of a large core leaving a deep *sink* The remaining holes are fired in volleys of four at a time in the ordinary way In this manner the shaft, which is in hard granite, is being deepened at the rate of 3½ or 4 fathoms a month Tonite is the explosive used

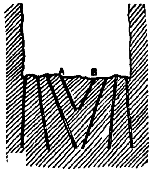


Fig 36

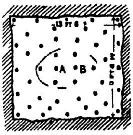


Fig 37

Sundry machines have been invented and used for driving levels without blasting Some cut up the face into small chips which can easily be removed, but they have not made their way at present into ordinary mining The Bosseyeuse of MM Dubois and François acts on a different principle It is a strong machine worked by compressed air It first of all drills holes 4 inches in diameter by percussion, a striking head is then substituted for the drill, and wedges, on the principle of the plug and feathers are inserted into the holes, and powerful blows with the striking head wedge off the rock in lumps This machine is being used with success in Belgium for driving levels and crosscuts in fiery mines

---

[1] *Oesterreichische Zeitschrift für Berg und Huttenwesen*, 1881.

Some comparative experiments between hand labour, a percussive drill, and a rotatory drill have lately been made in one of the Freiberg mines,[1] and the results are of much interest and importance The actual figures are as follows, the cost including in the case of the machines, interest, depreciation, and cost of repairs, and cost of steam power, supposing water power not available —

	Hand boring	Schram s Drill	Brandt s Drill
Distance driven per week (in metres)	0 9	4 5	5 0
Cost in marks per metre driven	1 0 to 123 5	77 4 to 85 25	74 34
Wages realized by the miners in marks per 8 hours shift	1 85 to 2 05	3 48 to 3 66	3 76

The advantages of machine work are very marked indeed both as regards rate and cost of driving and wages earned by the men Brandt s rotatory drill did its work cheaper and faster than Schram s machine, but nothing is said in the original notice of the advantage of a machine driven by compressed air for ventilating workings such as advanced headings in which these drills are employed

Brandt s machine was worked with water at a pressure of 83¼ atmospheres, of which 56 6 atmospheres were obtained by pressure pumps provided with an accumulator and 26 9 atmospheres by natural fall, owing to the working level being 277 metres below the pumps The water was conveyed to the machine in iron pipes of 1½ inches diameter inside The diameter of the holes bored was 2¾ inches and they could be bored in gneiss at the rate of 1½ inches per minute The stretcher bar on which the machine is carried is hollow and has a piston which can be forced out by hydraulic pressure so as to fix the bar firmly A similar bar is sometimes used with percussive drills [2]

As a method of breaking ground the ancient process of fire setting requires to be mentioned Before blasting was known it was largely employed, but its use is now confined to a few places on the Continent where the rocks are exceedingly hard and where wood is abundant and cheap Piles of wood are heaped up against the face of the workings and set on fire On returning to the working place two or three days afterwards when the rocks have cooled a little it is found that the ground has split and flaked off and that much has been loosened which can be removed by the pick and wedge

We finally come to water as an agent for removing rocks Streams of water were formerly used in South Wales for working beds of clay ironstone at the outcrop The water washed away the clay and shale and left the clean nodules of ironstone The china clay of Cornwall is also worked by water a stream of water is turned on to the soft mass and the workman loosens the ground with a pick the water carries off the particles of decomposed rock in suspension to regular settling pits Water under pressure has rendered vast services to the miner in working auriferous alluvia The system is described and figured at p 746 of vol x so it is unnecessary here to enter into details In the special case of salt mines recourse may be had to the solvent action of water directed by suitable jets for making excavations

Modes of paying miners

5 *Principles of Employment of Mining Labour*—As a large proportion of the expenditure in mining is for actual manual labour, it is very important that means should be taken to prevent any waste in this department Three principles are in vogue—payment by time, by work done either measured or weighed, and by the value of the ore extracted

The overseers, called captains in many metal mines are naturally paid by the month, and where strict supervision can be exercised, such as is possible at the surface, on the dressing floors for instance, the same principle may be adopted, but when men are working underground, and often in small gangs of only two or three persons at some distance apart, piecework of some kind is more economical and satisfactory in every way

In driving levels and sinking shafts it is usual for the men to work at a certain price per running yard or fathom The agents have to see that the excavation, whether shaft or level, is maintained of the full dimensions agreed upon, and preserved in the proper direction At the end of a certain time, generally a month, the work is measured by the agent From the gross amount obtained by multiplying the price by the number of fathoms driven or sunk it is necessary to deduct the cost of the materials supplied to the men by the mining company, such as explosives, steel, candles, &c, and the remainder is divided among the persons who took the contract When the useful mineral is being obtained the men may be paid at so much per cubic yard or fathom excavated, or at so much per ton of mineral extracted, the overseer of course has to see, in this latter case, that worthless rock is not sent to the surface Payment by the number of inches bored is a method in use in some countries, where the men are not experienced or enterprising enough to undertake the work in any other way A foreman points out to the men the position and direction in which the holes must be bored, measures them when completed, and subsequently charges and fires them

The third method is that which is known as the tribute system The miner working on tribute is allowed to speculate upon the value of the ore in a certain working area assigned to him and called his *pitch* He gives the mining company all the ore he extracts at a certain proportion of its value, after he has paid all the cost of breaking it, hoisting it to the surface, and dressing it Thus, supposing he takes a pitch at 5s in the £, and produces marketable copper ore of the value of £50, his share will be 50 × 5s = £12, 10s, less the cost of the materials he has been supplied with, and all expenses for winding, dressing, sampling, &c

6 *Means of Securing Excavations by Timber, Iron, and Masonry*—The following kinds of timber are those most frequently employed for securing excavations underground oak, larch, pitch pine, spruce fir, and acacia In many mines the timber is attacked by dry rot, which gradually renders it useless, and when the timber has often to be renewed the expense may be very considerable Various methods of preventing dry rot have been tried with more or less success, such as letting water trickle over the timber in the mine or treating it with preservative solutions beforehand Brine, creosote, and solutions of chloride of zinc, sulphate of zinc, sulphate of copper, and sulphate of iron increase the duration of timber It was found by experiments carried on at Commentry during a long series of years that one of the best plans was to soak the timber for twenty four hours in a strong solution of sulphate of iron The total cost was only ½d per yard of prop, whilst the timber lasted eleven times as long as when this simple treatment was omitted

Timber is used in various forms—either whole and merely sawn into lengths, or squared up, or sawn in half, or sawn into planks of various thicknesses

Where the roof of a bed is weak it may be kept up by simple props but in some coal mines and clay mines a better support is obtained by logs (*chocks*) laid two by two crosswise (fig 38)

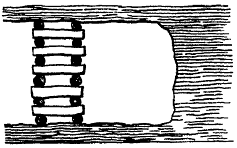


Fig 38

Though a level is an excavation of a very simple nature the methods of timbering it vary considerably, because the parts requiring support may either be the roof alone, or the roof and one or two sides, or the roof, sides, and bottom

If the roof only is weak as is the case with a soft lode between two hard walls a *cap* with a few boards resting on it (fig 39) is sufficient to prevent falls If one side is weak the cap must be supported by a side prop or *leg* (fig 40), and very often by two legs. The forms of joint between the cap and leg are numerous (fig 41), depending to a great extent upon the nature of the pressure, whether coming upon the top or sides With round timber the top of the leg is sometimes hollowed as shown in fig 42 A but occasionally the joint is flat and a thick nail, or *nog*, is put in (fig 42 B) to prevent the effects of side pressure, or, better, a piece of thick plank is nailed under the cap (fig 43) Where the floor of a level is soft and weak, a sole piece or *sill* becomes necessary, and, if the sides or roof are likely to fall in a lining of poles or planks is used (fig 43)

---

[1] *Jahrbuch fur das Berg und Huttenwesen im Konigreiche Sachsen auf das Jahr* 1882 p 18 and abstract in *Proc Inst Civ Eng*, vol lxix, 1881 82 part iii p 51

[2] *Annales des Mines*, ser 8, ii, pl 1, fig 6, 1882

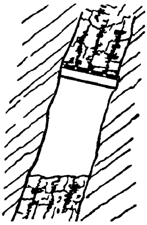


Fig 39

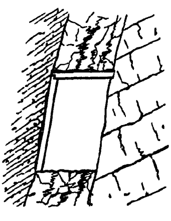


Fig 40

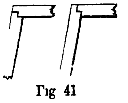


Fig 41

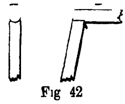


Fig 42

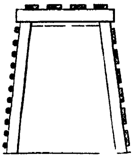


Fig 43

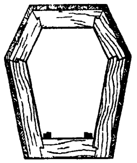


Fig 44

In some very heavy ground in the Comstock lode a special system of timbering is adopted (fig 44)

If the ground is loose, so that the roof or sides, or both, will run in unless immediately supported, the method of working called *spilling* or *poling* is pursued It consists in supporting the weak parts by boards or poles kept in advance of the last frame set up The poles or boards (*laths*) are driven forward by blows from a sledge, and the ground is then worked away with the pick, as soon as a sufficient advance has been made a new frame is set up to support the ends of the poles or boards and the process is repeated (figs 45 and 46) In running ground it is necessary to have the laths fitting closely together, and the working face also must be supported by *breast boards* kept in place by little struts resting against the frame These are removed and advanced one by one after the laths in the roof and side have been driven beyond them

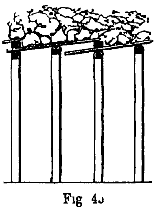


Fig 45

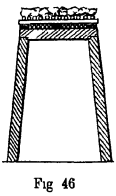


Fig 46

On account of the high price of timber, iron is sometimes employed in its place One method in use in the Harz consists in bending a rail into the form shown in fig 47 and making it support other rails laid longitudinally against which flattish stones are placed the vacant spaces are then filled with rubbish

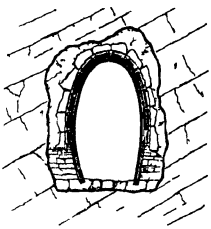


Fig 47

Masonry has long been used for supporting the sides of mining excavations The materials necessary are stone ordinary bricks, or slag bricks and they may be built up alone (*dry walling*) or with the aid of mortar or hydraulic cement The bottom of a level is occasionally lined with concrete to carry a large stream of water which otherwise might run into lower workings through cracks and crevices Dry walling is not uncommon, and it may be combined with the use of timber (or iron) as shown in fig 69 in which a level is maintained between two walls keeping back a mass of rubbish

48 and 49 show methods of securing a drift by arches when a has been removed.

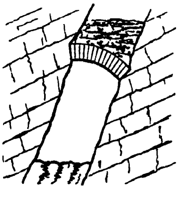


Fig 48

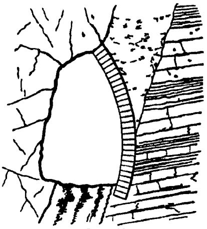


Fig 49

Timbering for shafts

The timbering required for shafts varies according to the nature of the ground and the size of the excavation A mere lining of planks set on their edges (fig 50) suffices for small shafts, corner pieces being nailed to keep the successive frames together In some of the salt mines of Cheshire the shafts are lined with 4 inch planks united by mortice and tenon joints

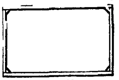


Fig 50

The usual method of securing shafts is by *sets* or *frames* Each set consists of four pieces, two longer ones called *wall plates* and two shorter ones called *end pieces* They are joined by simply halving the timber as shown in fig 51 A more complicated joint (fig 52) is often preferred The separate frames are kept apart by corner pieces (*studdles*, Cornwall, *jogs* Flintshire), and loose ground is prevented from falling in by boards or poles outside the frames

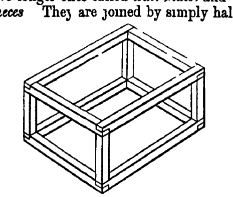


Fig 51

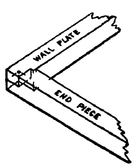


Fig 52

As shafts are frequently used for the several purposes of pumping, hoisting and affording means of ingress and egress by ladders, it becomes necessary in such cases to divide them into compartments Pieces of timber parallel to the end pieces (*buntons* or *dividings*) are fixed across the shaft, and serve to stay the wall plates and carry the guides as well as to support planks (*casing boards*) which are nailed to them so as to form a continuous partition or brattice The magnificent timbering of some of the shafts on the Comstock lode is described by Mr James D Hague as follows [1]—"The timbering consists of framed sets or cribs of square timber, placed horizontally, 4 feet apart, and separated by uprights or posts introduced between them Cross timbers for the partitions between the compartments form a part of every set The whole is covered on the outside by a lagging of 3 inch plank placed vertically" Figs 53, 54 and 55, copied from Mr Hague's plates, illustrate this method

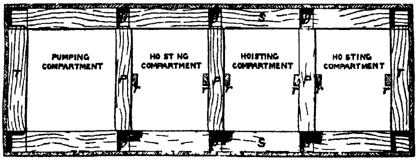


Fig 53

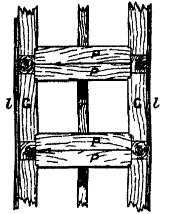


Fig 54

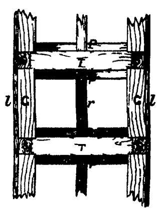


Fig 55

---

[1] nited States *Geological Exploration of the Fortieth Parallel* vol iii, ing Industry p 103

of timbering Fig 53 is a plan of the shaft "S, S are the longitudinal or sill timbers, T, T the transverse end timbers, P partition timbers, *r* guide rods between which the cage moves, *q* gains cut in the sill timbers, to receive the ends of the posts The sheathing or lagging is seen enclosing the whole frame" Fig 54 is a transverse section through the partition P of fig 53, "between the pumping compartment and the adjoining hoisting compartment, looking towards the latter In this figure, G, G are the posts, S the sill timbers, P the partition timbers, the ends of which are framed with short tenons that are received in gains cut in the sill timbers and the ends of the posts, *r* guide rod, *l* lagging or sheathing Fig 55 is an end view of the frame shown in fig 53 "The single piece T forms the end, while the double pieces P forming the partitions are seen beyond "The outer timbers of each set, that is, the two sides and ends of the main frame, are 14 inches square, the posts, ten in number, four at the corners and two at each end of the three partitions, are of the same size The dividing timbers, forming the partitions, are 12 inches square

When ground is loose or running, recourse must be had to a *spilling* process like that described for levels Strong balks of timber are fixed at the surface or in solid ground, and then the first frame is hung from these *bearers*, and each successive frame from the one above it Iron bars with cotters may be used for suspending the sets, but on the Comstock lode each bolt is made in two parts with a tightening screw in the middle, and the sets can thus be kept very firmly together The laths are driven in advance, in the manner explained in the case of levels, and a new frame is put in as soon as the excavation has been sufficiently deepened within the protecting sheath of boards In very unstable ground it may be necessary to put in the frames touching each other, so that the shaft becomes encased in a solid box of timber, occasionally 14 inches thick

Masonry for shafts

Like levels, shafts may be lined with masonry or brickwork, and these have the advantage of being far more permanent than timber, and of requiring fewer repairs This kind of shaft lining is especially desirable in the loose ground near the surface, because, if the working is discontinued temporarily, the shaft still remains secure and available for use at any future time, whereas if timber is put in it often decays, the top of the shaft collapses, and much expense is incurred in the process of reopening it The section of the shafts that are walled is generally circular as affording the best resistance to pressure, but elliptical walling is also met with Another shape is like a rectangle save that the sides, instead of being straight form curves of large radius The walling may be dry or with mortar, according to circumstances

The masonry is put in either in one length or in successive portions in descending order, and this is the usual plan The shaft is sunk a certain depth, with temporary timbering if necessary, and when firm ground has been reached a bed is cut out round the shaft and on this is placed a crib or curb AB (fig 56)[1] consisting of segments of timber which form a ring This serves for a foundation for the brickwork, which is built up to the surface, the temporary timbering is removed, and the space filled up with earth or concrete Sinking is then resumed below the curb, and for a certain distance of a smaller diameter, so as to leave a bracket or ledge, to support the first curb On arriving after a certain depth of sinking, at another firm bed, a second curb CD is put in and a portion of brickwork built up When the ledge of rock is reached it is carefully removed in small sections and the brickwork brought up to the first curb This process is repeated till the shaft is completed, or reaches rock in which no masonry is requisite If owing to the nature of the ground, it is impossible at first to find a firm seat for the curbs, it becomes necessary to hang them by iron bolts from a strong bearing frame at the surface

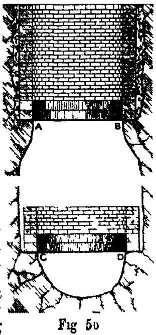


Fig 56

When shafts pass through very watery strata it is most desirable to stop all influx into the mine for the purpose of saving the heavy expense of pumping The manner in which this is effected by a watertight lining, known as tubbing, is described in the article Coal, vol vi p 62, where will also be found an account of Triger's plan of sinking shafts with compressed air, and the very successful method of boring shafts through water bearing ground invented by Messrs Kind & Chaudron

Exploitation

7 *Exploitation, or Working Away of Veins, Beds, and Masses* —We have described how shafts are sunk and levels driven, and we now come to the processes employed in removing the mineral

The deposit must first of all be reached by a shaft, or, where the contour of the country permits it, by a level In the case of a vein an exploratory shaft is often sunk on the course of the lode for 20 or 30 fathoms, and, if the indications found in a level driven out from this shaft warrant further prosecution of the mine, a first working shaft is sunk to intersect the lode at a depth of 100 fathoms or more from the surface Crosscuts are then driven out at intervals of 10, 15, or 20 fathoms to reach the lode, as shown in fig 57, which represents a section at right angles to the line of strike Sometimes the main shafts are carried down all the way along the dip of the deposit, though perpendicular shafts have the advantages of quicker and cheaper winding and [illegible] pumping, to say nothing of the possibility of utilizing the cages for the rapid descent and ascent of the miners If an inclined shaft appears to be advisable, great care should be taken to sink it in a straight line In either case levels are driven out along the strike of the lode as shown in the longitudinal section fig 58, in the hopes of meeting with valuable ore-bodies such as are represented by the stippled portions of the figure For the purpose of affording ventilation, and still further exploring the ground and working it, intermediate shafts, called *winzes* (Cornwall) or *sumps* (North Wales), are sunk in the lode

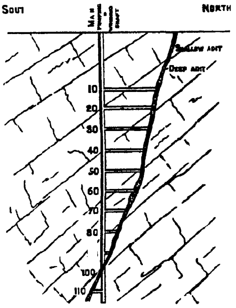


Fig 57

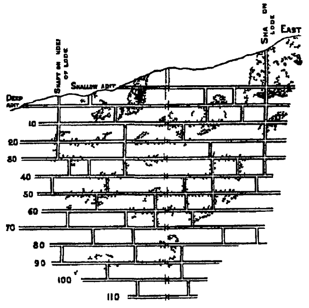


Fig 58

The actual mode of removing the lode itself depends a good deal upon circumstances, viz, its width the nature of its contents and the walls that enclose it but the methods of working may generally be brought under one of two heads, viz, underhand stoping or overhand stoping The word *stope* is equivalent to step and the term stoping means working away any deposit in a series of steps *Underhand* or *bottom stopes* are workings arranged like the steps of a staircase seen from above whilst *overhand* or *back stopes* are like similar steps seen from underneath Both methods have their advantages and disadvantages, and both are largely used

We will first take underhand stoping as this is the older method In the old days the miner began in the floor of the level (fig 59), and sank down a few feet, removing the part 1 he followed with 2, 3, 4, &c until the excavation finally presented the appearance shown fig 60 Any valueless rock or mineral was deposited upon platforms of timber (*stulls*), and the ore was drawn up into the level

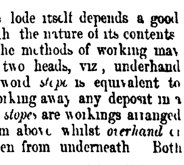


Fig 59

---

[1] J. Callon, *Lectures on Mining*, vol i Atlas, plate xxviii

by a windlass One great disadvantage of this method is that the ore and water have to be drawn up some distance by hand labour , much timber is required for the stulls if there is a large quantity of worthless stuff in the vein or if the sides are weak The advantages are that ore can be worked away as soon as the level is driven that the men are always boring downwards and lastly that the ore can be carefully picked after it is broken without fear of any valuable particles being lost

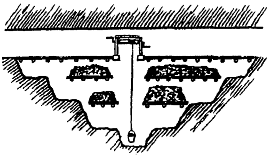


Fig 60

A more economical method of working by underhand stopes and one largely employed in Cornwall at the present day consists in reserving any attack upon the ore ground until a lower level has been driven An intermediate shaft (winze) between the two levels is then made either by sinking from the upper level or rising from the lower one The work of stoping is commenced at the two upper ends of the winze and the lode is removed in a succession of steps the workings assuming the appearance exhibited in fig 61 The steps are generally made steep so that the ore may readily roll into the winze and so that the bore holes may do better execution but these steep stopes are dangerous if a man happens to slip and fall The huge open chasms left by the removal of a large lode in this way are also a source of danger for there is always a risk of falls of rock and from places which cannot easily be examined

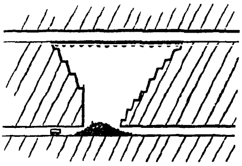


Fig 61

Figs 62 and 63 kindly supplied by Captain Josiah Thomas[1] explain the general arrangement of the workings of the largest tin mine in Cornwall The lode after producing copper ores to a considerable depth changed its character and became rich in tin The workings for tin ore are confined almost entirely to the granite The section fig 62 shows that the main shaft of the mine is at first vertical and then carried down on the dip of the lode

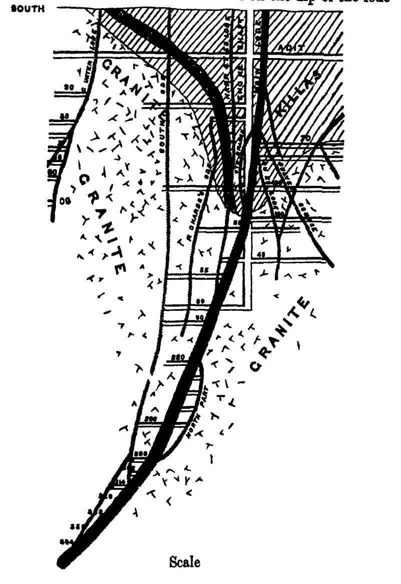


Fig 62 —Transverse Section Dolcoath Mine Cornwall

The process of overhand stoping is precisely the reverse of that which has been just described the work is commenced from a rise (fig 64 A) or better from the two bottom ends of a winze (fig 64 B) As soon as the men have excavated a sufficient height of the roof of the level they put in strong pieces of timber from wall to wall, and

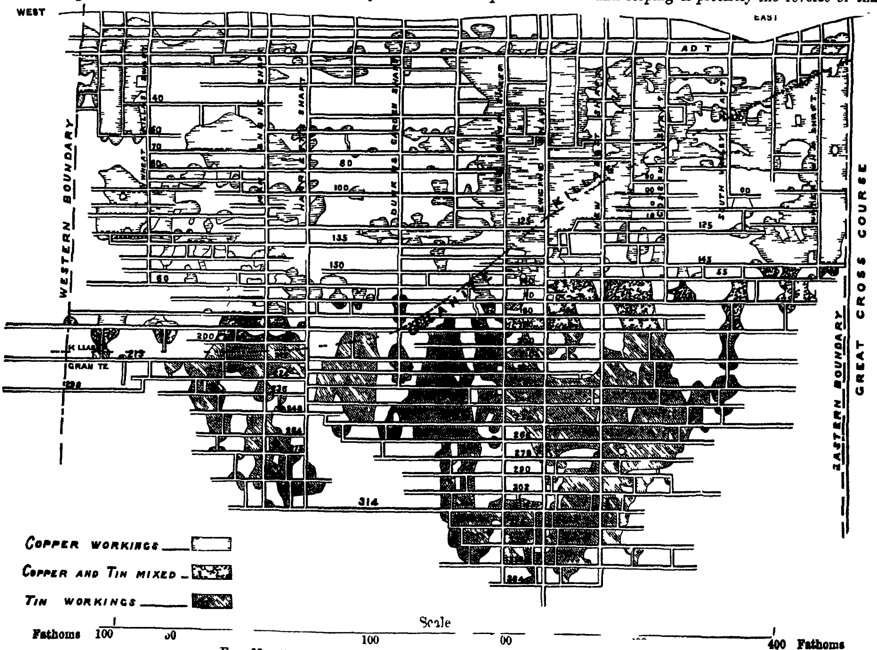


Fig 63 —Longitudinal Section Main Lode Dolcoath Mine Cornwall

cover these cross pieces (*stempels, stull pieces*) with boards or poles, and throw down the rubbish upon the platform (*stull, bunning*) thus formed In the midst of the rubbish chimney like openings (*mills, passes*) are reserved, lined with boards or dry walling, and closed at the bottom with shoots provided with doors The ore is thrown into these passes which are tapped when necessary, the ore falls into the tram waggon placed ready to receive it

---

[1] See *Report of Miners Association of Devon and Cornwall for* 1882 and R J Frecheville *Trans Roy Geol Soc Cornwall* vol x part v

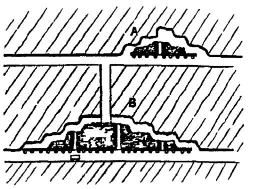


Fig 64

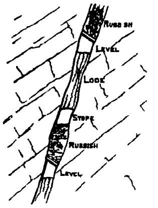


Fig 65

Fig 65 gives a transverse section showing the rubbish resting on the stull This is what may be called the typical method of stoping when the lode affords rubbish enough for the men to stand on and to keep them close to the rock they are attacking Very often such is not the case and the whole of the lode has to be sent to the surface for treatment If the walls are firm the lode is sometimes stoped away, a stull put in, and a sufficient heap of broken ore is left upon the stull to give the men good standing ground the excess is thrown over the ends of the stull or the great heap is tapped by cutting a hole in the stull covering and allowing a quantity to run down into the level

Another method consists in putting in temporary stages upon which the men stand to do their work whilst the excavation is left as an open space (fig 66) This mode of working is incompatible with weak walls If a lode does not afford rubbish enough for completely filling up the excavated space, or if it is too narrow for men to do their work comfortably one of the walls may be cut into and blasted down (fig 67) so that the men always stand upon a firm bed of rubbish while at work and there is no fear of a collapse of the mine In certain special cases rubbish is sent down from the surface to fill up the excavations

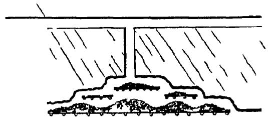


Fig 66

The advantages of overhand stoping are—that the miner is assisted by gravity in his work that no ore or rock has to be drawn up by hand labour, and that less timber is required On the other hand the miner is always menaced by falls, but as he is close by he can constantly test the solidity of the roof and sides by sounding them with his sledge there is the further disadvantage that particles of ore may be lost in the rubbish, but this loss is often prevented by laying down boards or sheets of iron while the lode is being broken down

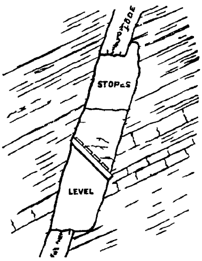


Fig 67

When very wide lodes come to be worked recourse is often had to special methods The great lode at the famous Van mine in Montgomeryshire is sometimes 40 feet in width and the hanging wall is weak The lode is stoped away overhand, and the cavities packed with rubbish part of which is derived from the lode itself, whilst the greater portion is supplied from a special quarry at the surface Fig 68[1] explains the details of the case A is the original cross cut (not in the line of section) by which the lode was reached, B is the *flucan*, C the bastard lode, generally worthless, E the main lode, H permanent levels, and K *ore pass* reserved amidst the rubbish (*deads*) D, I *pass* down which rubbish is shot, N crosscut connecting the level H with P the permanent level in the *country*

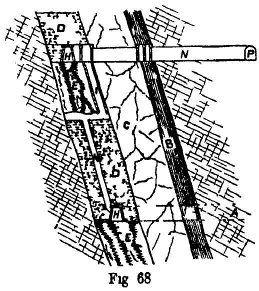


Fig 68

If the lode is not firm enough to allow of the stopes being carried for its full width, the crosscut method is adopted, the workings in this case instead of proceeding along the strike, are carried across the deposit from one wall to another

The lode is removed in successive horizontal slices A, B, C, D, E, and for each slice a level (L, fig 69) is driven, either in the lode, or partly or entirely in the country from this level crosscuts are put out 6 or 8 feet wide as shown in the plan (fig 70) These are regularly timbered according to the necessities of the case and when No 1 is completed No 2 is begun and the rubbish from No 2 thrown into the empty space of No 1 crosscut If the quantity is insufficient deads are brought in from the surface or from exploratory workings in worthless rock in the neighbourhood Sometimes the crosscuts are not driven side by side but 1 and 5 would be driven first leaving 2 3 and 4 as a solid pillar then 3 would be worked away and finally 2 and 4 between the timber and rubbish on each side The greater part of the timber can be recovered when the next slice above is taken off as the props are put in with the small ends downwards and can be drawn up with levers M (fig 69) is a level reserved in the deads for traffic and ventilation This method of working is applicable not only to lodes but also to irregular masses

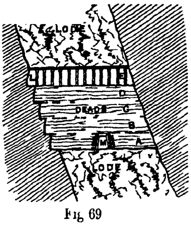


Fig 69

Fig 70

In working away the soft bonanzas or ore bodies of the great Comstock lode which are from 10 to 30 or even 40 or 50 feet wide and which are enclosed in very unstable ground a special method of timbering is employed (figs 71 and 72) It consists in framing timbers together in rectangular sets each set being composed of a square base placed horizontally formed of four timbers sills, and cross pieces 4 to 6 feet long framed together surmounted by four posts 6 to 7 feet high at each corner and capped by a frame work similar to that of the base These cap pieces forming the top of any set are at the same time the sills or base of the next set above, the posts as the sets rise one above the other in the stope being generally placed in position directly over those below The timbers are usually of 12 inch stuff square hewn or sawn Each post has a tenon 9 inches long at the upper end and a tenon of 2 inches at the lower end which fit into mortices in the cap and sill respectively and "the sills and caps have short tenons on each end and shoulders cut to receive the ends of the post and the horizontal cross pieces The walls of the excavation are sustained by a lagging of 3 inch or 4 inch plank The whole width of the ore body is stoped away at once, and its place supplied by timbering and finally the vacant space is filled with waste rock derived from dead work in the mine or from special excavations —underground quarries in fact,—in barren ground The stoping is carried on overhand, starting from an intermediate shaft or winze, and fig 73 will explain how the different frames are built up one above the other

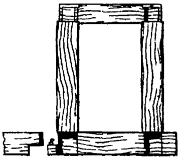


Fig 71

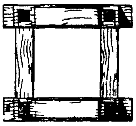


Fig 72

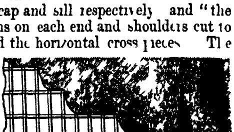


Fig 73

Another method of working a wide lode is to attack it in slices parallel to the dip, working away each slice separately as if it were a lode of ordinary dimensions, and filling up with rubbish (fig. 74).

---

[1] C Le Neve Foster Note on the Van Mine, *Trans Roy Geol Soc Cornwall* vol x p 41

[2] James D Hague *United States Geological Exploration of the Fortieth Parallel* vol iii "Mining Industry" p 112

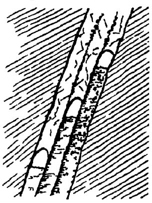


Fig. 74.

Working of beds

We now come to beds or seams. The mode of working the most important beds that occur in the earth's crust, viz., coal seams, has already been described in the article COAL (vol. vi. p. 64 sq.), and details have been given concerning the removal of the mineral by pillar working and long wall working. Both these methods are applicable in the case of seams of other minerals. Such for instance are the beds of fire clay and clay ironstone which are wrought by both the processes just mentioned, and often in connexion with coal.

Next in importance to coal is ironstone, and a brief account of the workings in the Cleveland district will explain the manner in which more than one third of the iron ore raised in the British Isles is obtained by mining. It resembles the "bord and pillar" system used for working coal in Durham.

Cleveland

The Cleveland ore occurs in the form of a bed from 6 to 16 feet thick in the Middle Lias, lying pretty level. A mainway (fig. 75) driven about 12 feet wide for a considerable distance and at right angles to it *bords* are driven 5 yards wide for a length of 30 yards and then at right angles a *wall* 7 or 8 feet wide and 20 yards long. By drivages of this kind the bed is cut up into pillars or blocks 30 yards long by 20 yards wide. The pillars are subsequently removed in the following way. A *place*, or drift *ab* 6 feet wide, is driven across the pillar 10 yards from the corner, and portions (*lifts*) about 6 yards wide are worked away in the order 1, 2, 3. After No. 1 lift has been removed, the timber put in to support the roof temporarily is withdrawn, and the roof is allowed to fall; No. 2 is then taken, and No. 3 in the same way. While these lifts are being taken out, another place *cd* is being driven across the pillar 10 yards from the first, and the pillar removed entirely by a series of fresh lifts.

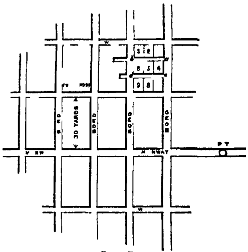
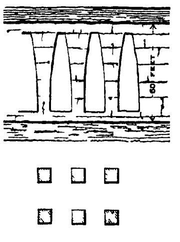


Fig. 75.

Gypsum quarries

Fig. 76 represents in section and plan the chambers and pillars of the underground gypsum quarries which supply the well known plaster of Paris to all the world.[1] The principal bed is from 50 to 60 feet in thickness; pillars are left 10 feet square at the base and the *stall* between them are 16 feet wide. The workings are slightly arched, and are not carried up to the roof, for the purpose of better maintaining the security of the chambers, because heavy damages would have to be paid if they "caved in" and rendered the surface useless. A similar layer left for the floor prevents *creep* (see COAL, vol. vi. p. 64), and enables the underground roads to be kept in good repair.



quarries

Underground slate quarries afford examples of very various methods of removing thick beds of mineral of comparatively little intrinsic value. At Angers in France, where the beds dip at a high angle, the underground workings are carried on like an open quarry under a strong roof of slate; the floor is continually being worked away in steps, and an immense open chamber is left. In the Festiniog district in North Wales the principal bed, or *vein* as it is called, is more than 100 feet thick in places, and the method of working consists in making alternate pillars and chambers each 30 feet to 50 feet wide along the strike (cross section and plan figs. 77 and 78). The pillars follow lines of natural cross rending PP', which commonly make an angle of 25° to 35° with the direction of the dip. The excavations are arranged in regular lines, and form continuous chambers extending very often from the surface to the very lowest workings. A, B, C, D are the original working levels. The slate of the supporting pillars is entirely lost, as these cannot be removed with safety. This method of working requires a strong roof. In the Ardennes, on the contrary, the pillars are carried along indefinitely along the strike (fig. 79, cross section). The slate in each longitudinal chamber is removed in slices parallel to the bedding, and the men stand upon the rubbish, which finally fills up the chambers completely.

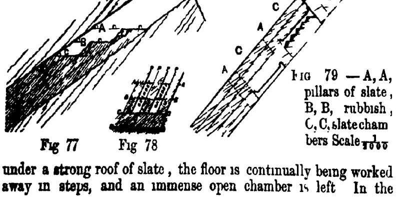


Fig. 77. Fig. 78.

Fig. 79.—A, A, pillars of slate; B, B, rubbish; C, C, slate chambers. Scale $\frac{1}{1000}$.

Salt mi

Rock salt constitutes another important mineral which occurs in the form of stratified deposits. The principal source of the Cheshire salt is a bed 84 feet thick lying horizontally, but only the bottom part, 15 feet to 18 feet thick, is mined. Pillars 10 yards square are left promiscuously about 25 yards apart, as shown in fig. 80, which represents part of Marston Hall rock salt mine.[2] The workings are advanced by making in the upper part an excavation 5 feet 9 inches high, called the *roofing* (*a*, fig. 81), and then the lower two thirds of the part worked are removed by blasting slanting holes. Many of the old salt mines have collapsed from weakness of the roof or insufficiency of the pillars, and have become inundated; the brine is then extracted by pumping and evaporated for salt.

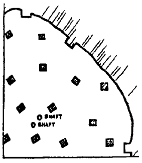


Fig. 80.

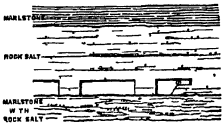


Fig. 81.

In some countries, especially when the beds of salt are impure or much mixed with clay or shale, the formation of brine is conducted regularly by making a network of drivages within a rectangular, elliptical, or circular area in thick beds of saliferous marl, and then introducing fresh water by pipes, so as to form underground pond which gradually dissolve the roof and sides. The brine is drawn off and either pumped up or conveyed by adits to the surface.

Open workings.

A few words remain to be said about open workings. Some minerals are always obtained in this way; others are worked open before regular underground mining begins; and, thirdly, it often happens that underground and surface work are both carried on simultaneously on the same deposit. Among deposits worked open cast are peat, numerous kinds of stone, iron ore, cupreous pyrites, lead ore, gold and tin bearing alluvia, and diamantiferous rock.

Owing to its soft, spongy, and fibrous texture and the fact of its often lying below the water level, peat has to be worked in a special manner. Trenches are dug about a foot deep with a sharp spade, which cuts out sods of convenient size for drying and burning. When one layer has been removed in this way, another is taken off, and so on. If water is reached the working can still be pursued by using the long spade (*grand louchet*, France) with a handle of 16 or 20 feet. It cuts out a sod 3 or 4 feet long at each thrust.

When a deposit is more or less solid the workings are frequently arranged in steps, the height and breadth of each depending upon the firmness of the rock.

In many cases the first work consists in removing worthless rock at the surface (*overburden*), and where the underlying deposit is thick or very valuable it will pay to remove a very great thickness of overburden, on account of the advantages of working a deposit open. These advantages are—entire removal of the deposit without loss in pillars, no expense for timbering or for packing with rubbish or for ventilating or lighting the workings, better ventilation, easier supervision, longer working hours, less danger.

As an example of a large open working may be mentioned the great Penrhyn slate quarry near Bangor, employing about 3000 hands, and worked by a succession of terraces on an average 60 feet high by 30 feet wide (fig. 82). Reference has already been made to the thick lead bearing sandstone of Mechernich, which is in part worked as an open quarry. Mokta el Hadid, near Bona in Algeria, and the Rio Tinto mines in Spain, afford instances of extensive combined open and underground workings for iron ore and cupriferous pyrites respectively.

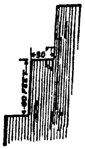


Fig. 82.

Local laws regulating the size of the working areas, or claims,

---

[1] Callon, *Lectures on Mining*, vol. ii. plate xli.

[2] Joseph Dickinson, "Report on the Salt Districts," *Reports of the Inspectors of Mines for the year* 1881, p. 63.

Diamond mines

owned by separate individuals or companies, considerably affect the methods of working This is especially the case with the diamond deposits of South Africa The diamantiferous rock at the celebrated Kimberley mine (formerly called Colesberg Kopje) occurs in the shape of an elliptical upright mass the greatest length being about 330 yards and the greatest breadth about 200 yards The superficial area is about 9 acres, the mass extends downwards within almost perpendicular walls of shale, and is worked in places to a depth of about 400 feet The claims are only 31 feet square and are more than four hundred in number and these have in some instances been subdivided into portions as small as the sixteenth of a claim but as at the present time one company may own very many claims the number of individual holdings is less numerous than formerly when the limit was two claims The working is carried on vertically downwards, and as the claims are not all worked at the same rate those that progress most rapidly are surrounded by perpendicular walls of neighbouring claims The shale or *reef* enclosing the deposit is constantly falling into the huge open pit and has to be cut away to a slope the expense of this work being charged to the claim holders generally by the mining board The diamantiferous rock is extracted by innumerable wire rope inclines

Evils attending hydraulic mining

We have already referred to the method of working gold bearing alluvia by the hydraulic process which has rendered such services in the United States (GOLD vol x p 746) At the same time one must not be blind to the evils of this method of working which have at last necessitated legislative interference Some idea of the extent of the mischievous results of hydraulic mining will be gathered from the statement that one working alone the Gold Run Ditch and Mining Company for the last eight years has been discharging 4000 to 5000 cubic yards of sand gravel and boulders daily for a period of five months each year into a tributary of the Sacramento As a natural consequence deposits are formed lower down the river obstructing the navigable channels rendering overflows more frequent and destructive and causing valuable land to be destroyed by deposits of sand The superior court of Sacramento county California has recently decided that the hydraulic mining companies must build dams to impound the coarse and heavy debris or take other efficacious means to prevent their being washed down the rivers

Underground transport

8 *Carriage or Transport of Minerals along the Underground Roads* —After the mineral has been broken down in a deposit it is necessary to pick out any barren rock and then convey to the surface all that is of value

Carriage by workers

The simplest and oldest method of transport along underground roads is carriage on the back, and this method may still be seen at the present day even in countries where the art of mining is generally highly advanced Thus, for instance, in the little slate mines near Cochem on the Moselle men and lads carry up all the blocks of slate upon their backs, walking upon steps cut in the rock they come up with their hands upon the ground bent almost double under the weight of the block, which rests upon a thick pad Again, the blocks of slate are still carried on the back from the actual working place to the nearest tram road, in the slate mines of the Ardennes In the Sicilian sulphur mines the same method is common, and it is found also in parts of Spain and China, where baskets are used, whilst bags are employed in Mexico and also in Japan Even in England the system still survives in the Forest of Dean, where boys carry iron ore in wooden trays from the very irregular ore producing cavities either to the surface or to the nearest shaft

Sledges

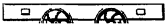
Sledges, or *sleds*, enable greater loads to be transported, but they are not available unless the conveyance is along roads sloping downwards They have been largely employed in coal mines, and are still resorted to in some collieries for conveying the coal from the working place to the nearest tram road

We next come to wheeled carriages The simplest is the wheelbarrow The barrow used in Cornwall at the present day is not unlike that figured more than three centuries ago by Agricola The navvy's barrow is more advantageous, but it requires a wider and higher level The barrow runs upon the natural floor of the level, upon boards, or upon thin strips of iron Carts drawn by horses may be used in large underground quarries Excepting in special cases it is advisable to replace barrows by waggons running upon rails The oldest form is the German *Hund* It consists of a rectangular wooden body, with four wheels, resting upon two boards as rails, and it is kept on the track by a pin which runs between the boards

Cast iron tram plates were introduced in the last century, and were finally succeeded by iron rails, which are now in general use, though steel threatens to displace iron in this as in other departments of mining Various forms of rail are employed The simplest is a bar of iron set on its edge in transverse sleepers, or flat iron nailed to longitudinal sleepers Small T headed and bridge rails are not uncommon In the Harz the rails sometimes lie on stone sleepers, a hole is bored in the stone, plugged with wood, and the rail is nailed on The gauge varies from 14 inches to 3 feet or more, 20 inches to 22 inches is a common gauge in metal mines Arrangements of course have to be made for passing from one line to another by *points*, but the transference is frequently best effected by putting down flat plates of cast iron, upon the smooth surface of which the waggons can be handled with ease and turned in any direction raised ledges guide the wheels into any particular track

The form and size of the waggons running upon the rails necessarily vary according to the size of the underground roads and the manner in which the mineral is raised in the shaft In some mines the practice exists of loading the mineral in the level into an iron bucket (*kibble*) standing upon a *trolley*, which is merely a small platform upon wheels This trolley is pushed (*trammed*) to the shaft, the full kibble is hooked on to the winding rope and drawn up, whilst an empty kibble is placed upon the trolley and trammed back along the level, where it is again loaded from a shoot (*mill pass*) or by the shovel The usual plan, however, is to have a waggon, which is tipped on coming to an enlargement of the shaft (*plat ledge*) where the level joins it These waggons may be made of wood or sheet iron, and of late years sheet steel for the body and cast steel for the wheels have been coming into favour

The most modern system in metal mines is to imitate collieries, and use waggons which are drawn up in cages Fig 83 represents the plain but strong waggon of the Van mines, consisting of a rectangular body of sheet iron resting on an oak frame, and provided with cast steel wheels The wheels are loose upon the axles, which themselves run loose in the pedestals The waggon is emptied by being run on to a "tippler, which enables it to be completely overturned with great ease A commoner plan is to construct the waggon with a hinged door at one end, and the contents are discharged by opening this door and raising the body



The motive power for tramming waggons along the levels of metal mines is generally supplied by men or boys though, where large quantities have to be extracted and where the roads are favourable recourse may be had to ponies and horses and the various kinds of mechanical haulage described in COAL vol vi p 69

Trains of cars are sometimes drawn along underground railways by locomotives they have the great disadvantage of polluting the air with the products of combustion and consequently they are not available unless the ventilation is very good A small locomotive of 2 horse power nominal is used on an 18½ inch track in the adit level of the Great Laxey mine (Isle of Man), now approaching a mile in length and full sized locomotives ply along the adit of the Rio Tinto mines Locomotives worked by compressed air improve the ventilation instead of injuring it, and are not a source of danger in cases where fire damp may be present, but, except in special cases, they cannot be worked so cheaply as engines fired with coal Conveyance by electric railroads underground has hardly gone beyond the experimental stage, but the results obtained at the Zaukeroda colliery in Saxony[1] show that electricity can be applied with profit in this department of mining

A few instances of transport by boats may still be met with The boats used in the underground canal at Klausthal are 31 feet long by 4 feet 6 inches wide and 2 feet 11 inches deep Each boat carries 5 or 6 tons

---

[1] *Jahrbuch für das Berg und Hüttenwesen im Königreiche Sachsen auf das Jahr* 1883, p 50

Where roads have a strong gradient, inclined planes are employed, either self acting if the mineral has to be lowered, or worked by stationary engines if the mineral has to be raised (see COAL, vol vi p 69)

9 *Winding, or Raising in the Shafts, with the Machinery and Apparatus required*—In speaking of the transport by underground roads, we mentioned that the mineral is occasionally brought to the surface on the backs of men or boys In other cases daylight is reached by adit levels provided with railroads, but in by far the greater number of mines it is necessary to hoist the mineral, and often much rubbish, up vertical or inclined pits generally known as shafts

In beginning to sink a shaft from the surface, or in sinking a winze, hand power applied by a windlass is sufficient The broken rock at the bottom of the shaft is shovelled into a wooden or iron bucket (*kibble*), which is drawn up by a rope passing round the barrel of the windlass When a depth of 20 or 30 yards has been reached it is more advantageous to introduce horse power, and the usual machine by which this power is applied, called a *gin* or *horse whim*, is a common sight in many metalliferous districts It consists of a vertical axis carrying a barrel or drum 8 to 12 feet in diameter, round which is coiled the rope, which after passing over a pulley hangs down the shaft The axis carries an iron pin at each end, the lower one working in a stone and the upper one in a socket in the span beam or cross bar of the supporting frame Under the barrel is a long driving beam to which a horse is harnessed, and, as will be readily understood, the kibble is drawn up or lowered down as the horse walks round It is most economical to have two kibbles, for then they balance each other

Where steam and water power are not available, a large number of horses or mules are sometimes harnessed to whims, and ore raised from depths of 200 fathoms These, however, are exceptional cases and, especially since the introduction of portable engines, the use of steam power even for comparatively small depths, such as 100 yards, is daily increasing In hilly districts water power is generally at hand, and huge reservoirs are frequently constructed for storing the rainfall, and so affording an adequate and constant supply It may be utilized by water wheels, turbines, and water pressure engines

There are three systems of winding by steam or water power which are in regular use —(1) by buckets (*kibbles*), baskets, or bags swinging loose in the shafts, (2) by boxes working between guides (*skips*, Cornwall), (3) by cages carrying one or more waggons

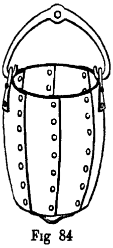


Fig 84

The buckets are made of wood sheet iron or sheet steel Their shape varies, it may be round or elliptical straight in the side or bulging in the middle Fig 84 represents a kibble made of sheet iron When the shaft is inclined the side upon which the kibble slides is carefully lined with boards (*bed planks*) resting upon cross sleepers Planks of hard wood like beech last longer and require fewer repairs than deal boards In the Harz poles fixed lengthwise take the place of boards which are customary in Great Britain Even where shafts are perpendicular a lining of planks is often put in round the winding compartment unless the space is considerable and the kibble then glides up smoothly, and there is less risk of accidents A more modern system is to use wire rope guides for the kibble which is thus kept from swinging about Another advantage of this plan is that a light cage can easily be substituted for the kibble and used for the ascent and descent of the men Mr Galloway has patented a method of sinking shafts with wire rope guides the upper ends of which are coiled upon drums at the surface By adopting this expedient the guides can be lengthened as the shaft is deepened

A word must be said about the actual loading and emptying of the kibble Sometimes, as already mentioned, the kibble is filled at the working place or from a shoot (*pass* Cornwall) carried down into the level, and then conveyed on a trolley to the shaft, where it is hooked on to the rope and drawn up More frequently the filler standing in the *plat* loads the kibble with a shovel, and in order to save time two kibbles are often provided, one being filled while the other is making the journey to and from the surface In this case it is necessary to have some kind of *clevis*, which will enable the kibble to be readily detached from the winding rope, and quickly and securely fastened on again On its arriving at the surface the *lander* seizes an eye or ring at the bottom of the kibble by a pair of tongs suspended by a chain, and the rope is now lowered The kibble is thus turned over and the contents fall into a tram waggon

The inconveniences of this method of winding are considerable, especially in inclined shafts where the direction and amount of the inclination are not constant There is great wear and tear of the bed plank and casing boards, and, unless constant attention is paid to repairs, places are worn out where the kibble catches, causing the rope to break The fall of a kibble and its contents not only does much damage to the shaft but also is a source of danger to the men The introduction of boxes (*skips*) working between guides or conductors was therefore a decided step in advance, for the system allows the winding to be carried on with less friction and with greater rapidity and safety The guides are often made of pieces of timber (like *r*, fig 53) bolted to the end pieces and dividings It is only in perpendicular shafts that guides made of wire rope or iron rods can be applied The skip is a box of rectangular section made of sheet iron or sheet steel, with a sloping bottom, and provided with a hinged door closed by a bolt for discharging its contents Fig 85[1] shows how the skip runs upon the guides by means of four cast iron or (better) cast steel wheels In an inclined shaft the guides sometimes have iron rails laid on them so as to diminish the wear Some of the skips in Cornwall are made to hold as much as a ton and a half of tin bearing rock The skip is filled with a shovel by a man standing in the plat, but a better plan is to arrange shoots leading from large hoppers, so that the ore can be made to run in without any shovelling The skip is sometimes tilted completely over instead of being emptied by a hinged door, this arrangement is in use in some of the German mines, where the skip is made of wood and is guided on each side by two pins or rollers running between two conductors When the skip has reached the surface two catches are made to support the lower rollers, whilst the upper ones pass through openings in the front guides, and the skip, turning upon the lower ones, is tipped over and so emptied

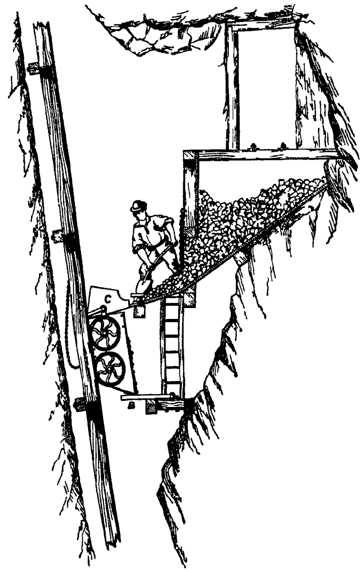


Fig 85

Cages

The most satisfactory system of winding is by cages, there is less handling of the mineral, and the hoisting proceeds at far greater speed This system, which is almost universal in collieries, is employed also for working deposits of other minerals and, though in vein mining the skip and kibble still prevail in England, the managers are beginning to recognize the advantages of the cage and equip their mines with more modern appliances than have hitherto been customary The cages used in the mines on the Comstock lode are very light and simple in construction as will be seen from fig 86 The cage in fact is a mere timber platform, 5 feet by 4,

---

[1] Moissenet, *Annales des Mines*, ser 6, vol ii, 1862, plate vii

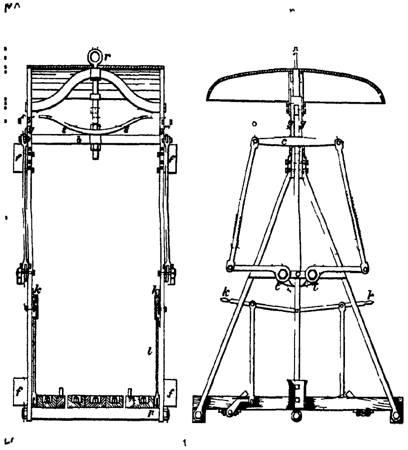


FIG 86 —Cage used in Comstock Lode

resting on iron bars, p and supported by iron rods on each side It is provided with a sheet iron bonnet to protect the men if they are inside, and also with safety catches t t which come into play if the rope breaks The hand levers k l at the ends of the cage raise up blocks which keep the car in its place during the ascent or descent g, g are guides for the end of the crossbar b c bar working teeth t, t by levers f "ear or "shoe embracing the guide rod in shaft, i, lifting bar, s, strong spring

The most important details concerning the use of cages, ropes and other hoisting appliances such as pulleys pulley frames detaching hooks and winding engines, have already been set forth in the article COAL, vol vi p 74 and it is therefore needless to repeat these particulars especially as the art of winding mineral cheaply speedily, and safely has been carried to a far greater pitch of perfection in collieries than in the majority of metal mines It is often convenient to fix winding engines underground for the purpose of sinking shafts and winzes and drive them by compressed air brought down in pipes from the surface

Koepe system The Koepe system of winding, which appears to be viewed with favour on the Continent, consists in having what is practically an endless rope with one large sheave over the shaft in the place of the two drums There are two cages and the rope below them acts as a counterbalance, so that the load is uniform throughout

chet method The most novel hoisting apparatus is that of M Blanchet (COAL vol vi p 76), which has now been regularly at work in the Hottinguer shaft at Épinac in France for the last six years M Blanchet's method consists in fixing in the shaft a large pipe in which is arranged a piston, from this is suspended a cage carrying waggons By exhausting the air above the piston the load is gradually forced up by the atmospheric pressure below it The Hottinguer shaft is 660 yards deep and the pipe is 5 feet 3 inches in diameter, made up of a succession of cylinders of sheet iron about $\frac{5}{16}$ inch thick and 4 feet 4 inches high joined by flanges and bolts The 485 rings composing the long pipe weigh altogether 418 statute tons The cage has nine decks and arrangements are made for unloading three at a time each waggon holds half a ton so that the total useful load is 4½ tons The speed of hoisting is 20 feet per second If two hoisting pipes are connected the dead weights may be made to balance each other, and the power required is simply that which is necessary to overcome the weight of the useful load All the men prefer the pneumatic hoist to the ordinary cage for descending and ascending the mine, and are regularly lowered and raised by it The advantages claimed by M Blanchet for this system are—(1) the possibility of hoisting from depths at which rope winding would no longer be practicable, (2) getting rid of the costly ropes and dangers connected with rope winding, (3) better utilization of the engine power, (4) improvement of the ventilation and diminution of the amount of fire damp

10. *Drainage* —The mineral having been raised to the surface, the task of the miner might appear to be at an end, but this is not the case, for it is further necessary that he should keep his mine free from water and foul air These two indispensable operations of draining and ventilating frequently require special appliances which add considerably to the general cost of mining

In all cases where it is possible, endeavours should be made to keep the water out of a mine, so as to save the expense of pumping it, and the method of putting in a watertight lining (*tubbing*) in a shaft has been already described (COAL, vol vi p 62) When large streams of water happen to be intersected by underground workings, and threaten to overpower the available pumping machinery, or when it is advisable to save the expense of draining abandoned workings, the entry of this water into the mine may often be prevented by stoppings called *dams*, constructed of timber or brickwork

In spite of all precautions, the miner generally has to contend with water which percolates into the workings Four methods of getting rid of this water are available viz, adits, siphons, winding machinery, and pumps

An adit, day level, or sough is a nearly horizontal tunnel with one end opening at the surface, allowing the water to drain away naturally In hilly countries mines are often worked entirely by adits, and even when a mine is deepened below the drainage level the utility of the adit is still threefold —it lessens the quantity of water which tends to percolate into the lower workings it lessens the depths to which the water has to be pumped, and, by furnishing a certain amount of fall, it enables water to be applied as power On account of these important advantages some very long and costly adits have been driven for the purpose of aiding the miners in certain metalliferous districts

Thus in the Harz the Ernest Augustus adit ("Ernst August Stolln") has been driven a distance of nearly 6¼ miles into the Klausthal district The total length of the adit including the branches, is no less than 14 miles It intersects many of the lodes at a depth of upwards of 400 yards from the surface The total cost of this adit is estimated at £8[illegible]500

Another long adit is the celebrated "Rothschönberger Stolln" which unwaters some of the most important mines at Freiberg in Saxony The length of the main or trunk adit is more than 8½ miles, the gradient of the greater part of it is only 1 18 inch in 100 yards The branches of this adit among the mines are more than 16 miles in length so that the total length of the main adit with its branches amounts to nearly 25 miles Many of the mines are now drained naturally to a depth of 250 to 300 yards The cost of the main tunnel was £359 334 or nearly £24 per yard but this includes the cost of eight shafts heavy expenses for pumping from these shafts the walling of the adit for ¾ mile and all general expenses The length of time occupied in driving this adit was thirty three years The Kaiser Josef II Erbstolln in Hungary is another remarkable mining tunnel which was commenced in 1782, and completed in 1878 at a total cost of 4 599 000 florins It is 10¼ miles in length extending from the valley of the river Gran to the town of Schemnitz, where it intersects the lodes at depths varying from 300 to 600 yards according to the contour of the surface

In Cornwall the Great County adit was driven for the purpose of relieving the Gwennap mines of their water and it was pushed on nearly to Redruth This adit differs from the great works undertaken in Germany by the fact that it commences in the mining district and though the length of all the drivages amounts to more than [illegible]0 miles, the water from the most distant mine does not run more than about 6 miles before reaching daylight The average depth is only 70 or 80 yards from the surface In fact this great adit though a work of great utility when the Gwennap district was in a flourishing condition, is merely a network of comparatively shallow drivages, often along the lodes themselves among the mines and therefore for boldness of execution cannot for one moment be compared to the great Schemnitz, Freiberg, and Klausthal drainage tunnels which have just been mentioned The Blackett Level in Northumberland is an adit which has been driven a distance of about 4¾ miles and it will have to be extended about 2 miles further before reaching Allenheads Its depth from the surface at this place will be about 200 yards

The main part of the Halkyn tunnel in Flintshire is 2 miles 1256 yards in length, and the branch driven out to Rhosesmor mine intersected the vein at a distance of 909 yards making a total of about 3¼ miles The greatest depth from the surface is 230 yards and the average depth in Halkyn Mountain about long by 4 feet 6 inches wide and 2 feet 11 inches deep Each boat carries 5 or 6 tons

Where roads have a strong gradient inclined planes are employed, either self acting if the mineral has to be lowered, or worked by stationary engines if the mineral has to be raised (see COAL, vol vi p 69)

9 *Winding, or Raising in the Shafts, with the Machinery and Apparatus required* —In speaking of the transport by underground roads, we mentioned that the mineral is occasionally brought to the surface on the backs of men or boys In other cases daylight is reached by adit levels provided with railroads, but in by far the greater number of mines it is necessary to hoist the mineral, and often much rubbish, up vertical or inclined pits generally known as shafts

In beginning to sink a shaft from the surface, or in sinking a winze, hand power applied by a windlass is sufficient The broken rock at the bottom of the shaft is shovelled into a wooden or iron bucket (*kibble*), which is drawn up by a rope passing round the barrel of the windlass When a depth of 20 or 30 yards has been reached it is more advantageous to introduce horse power, and the usual machine by which this power is applied, called a *gin* or *horse whim*, is a common sight in many metalliferous districts It consists of a vertical axis carrying a barrel or drum 8 to 12 feet in diameter, round which is coiled the rope, which after passing over a pulley hangs down the shaft The axis carries an iron pin at each end, the lower one working in a stone and the upper one in a socket in the span beam or cross bar of the supporting frame Under the barrel is a long driving beam to which a horse is harnessed, and, as will be readily understood, the kibble is drawn up or lowered down as the horse walks round It is most economical to have two kibbles, for then they balance each other

Where steam and water power are not available a large number of horses or mules are sometimes harnessed to whims, and ore raised from depths of 200 fathoms These, however, are exceptional cases and, especially since the introduction of portable engines the use of steam power even for comparatively small depths, such as 100 yards, is daily increasing In hilly districts water power is generally at hand, and huge reservoirs are frequently constructed for storing the rainfall, and so affording an adequate and constant supply It may be utilized by water wheels, turbines, and water pressure engines

There are three systems of winding by steam or water power which are in regular use —(1) by buckets (*kibbles*), baskets, or bags swinging loose in the shafts, (2) by boxes working between guides (*skips*, Cornwall), (3) by cages carrying one or more waggons

The buckets are made of wood sheet iron or sheet steel Their shape varies, it may be round or elliptical, straight in the side or bulging in the middle Fig 84 represents a kibble made of sheet iron When the shaft is inclined the side upon which the kibble slides is carefully lined with boards (*bed planks*) resting upon cross sleepers Planks of hard wood like beech last longer and require fewer repairs than deal boards In the Harz poles fixed lengthwise take the place of boards which are customary in Great Britain Even where shafts are perpendicular a lining of planks is often put in round the winding compartment unless the space is considerable and the kibble then glides up smoothly, and there is less risk of accidents A more modern system is to use wire rope guides for the kibble which is thus kept from swinging about Another advantage of this plan is that a light cage can easily be substituted for the kibble and used for the ascent and descent of the men Mr Galloway has patented a method of sinking shafts with wire rope guides the upper ends of which are coiled upon drums at the surface By adopting this expedient the guides can be lengthened as the shaft is deepened

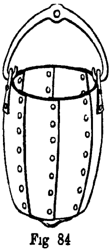


Fig 84

A word must be said about the actual loading and emptying of the kibble Sometimes, as already mentioned, the kibble is filled at the working place or from a shoot (*pass* Cornwall) carried down into the level, and then conveyed on a trolley to the shaft, where it is hooked on to the rope and drawn up More frequently the filler standing in the *plat* loads the kibble with a shovel, and in order to save time two kibbles are often provided, one being filled while the other is making the journey to and from the surface In this case it is necessary to have some kind of *clevis*, which will enable the kibble to be readily detached from the winding rope, and quickly and securely fastened on again On its arriving at the surface the *lander* seizes an eye or ring at the bottom of the kibble by a pair of tongs suspended by a chain, and the rope is now lowered The kibble is thus turned over and the contents fall into a tram waggon

The inconveniences of this method of winding are considerable, especially in inclined shafts where the direction and amount of the inclination are not constant There is great wear and tear of the bed plank and casing boards, and, unless constant attention is paid to repairs, places are worn out where the kibble catches, causing the rope to break The fall of a kibble and its contents not only does much damage to the shaft but also is a source of danger to the men The introduction of boxes (*skips*) working between guides or conductors was therefore a decided step in advance, for the system allows the winding to be carried on with less friction and with greater rapidity and safety The guides are often made of pieces of timber (like *r*, fig 53) bolted to the end pieces and dividings It is only in perpendicular shafts that guides made of wire rope or iron rods can be applied The skip is a box of rectangular section made of sheet iron or sheet steel, with a sloping bottom, and provided with a hinged door closed by a bolt for discharging its contents Fig 85[1] shows how the skip runs upon the guides by means of four cast iron or (better) cast steel wheels In an inclined shaft the guides sometimes have iron rails laid on them so as to diminish the wear Some of the skips in Cornwall are made to hold as much as a ton and a half of tin bearing rock The skip is filled with a shovel by a man standing in the plat, but a better plan is to arrange shoots leading from large hoppers, so that the ore can be made to run in without any shovelling The skip is sometimes tilted completely over instead of being emptied by a hinged door, this arrangement is in use in some of the German mines, where the skip is made of wood, and is guided on each side by two pins or rollers running between two conductors When the skip has reached the surface two catches are made to support the lower rollers, whilst the upper ones pass through openings in the front guides, and the skip, turning upon the lower ones, is tipped over and so emptied

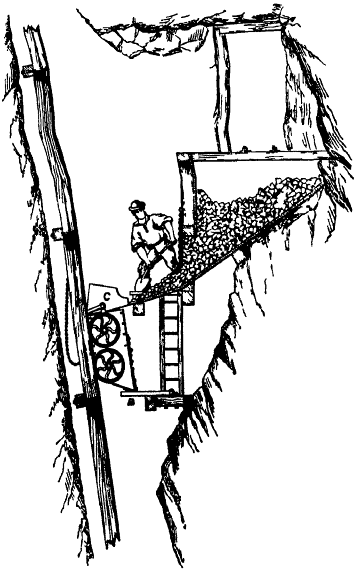


Fig 85.

The most satisfactory system of winding is by cages, there is less handling of the mineral, and the hoisting proceeds at far greater speed This system, which is almost universal in collieries, is employed also for working deposits of other minerals, and, though Cag in vein mining the skip and kibble still prevail in England, the managers are beginning to recognize the advantages of the cage and equip their mines with more modern appliances than have hitherto been customary. The cages used in the mines on the Comstock lode are very light and simple in construction, as will be seen from fig. 86. The cage in fact is a mere timber platform, 5 feet by 4, resting on iron bars p and supported by iron rods on each side. *It is provided with a sheet iron bonnet to protect the men if they are* inside, and also with safety catches t, t, which come into play if the rope breaks. The hand levers k, k, at the ends of the cage raise up blocks which keep the car in its place during the ascent or descent.

---

[1] Moissenet, *Annales des Mines*, ser 6, vol ii, 1862, plate vii

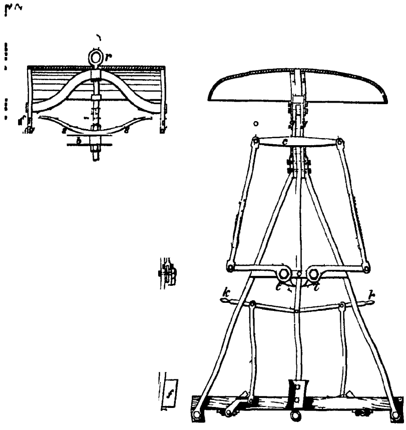


FIG. 86.—Cage used in Comstock Lode.

g, g are guides for the end of the crossbar *b*; *c*, bar working teeth *t, t* by levers *f*; "ear" or "shoe" embracing the guide rod in shaft; *r*, lifting bar; *s*, strong spring.

The most important details concerning the use of cages, ropes and other hoisting appliances such as pulleys, pulley frames, detaching hooks, and winding engines, have already been set forth in the article COAL, vol. vi. p. 74, and it is therefore needless to repeat these particulars, especially as the art of winding mineral cheaply, speedily, and safely has been carried to a far greater pitch of perfection in collieries than in the majority of metal mines. It is often convenient to fix winding engines underground for the purpose of sinking shafts and winzes, and drive them by compressed air brought down in pipes from the surface.

Koepe system. The Koepe system of winding, which appears to be viewed with favour on the Continent, consists in having what is practically an endless rope with one large sheave over the shaft, in the place of the two drums. There are two cages, and the rope below them acts as a counterbalance, so that the load is uniform throughout.

Blanchet's method. The most novel hoisting apparatus is that of M. Blanchet (COAL, vol. vi. p. 76), which has now been regularly at work in the Hottinguer shaft at Épinac in France for the last six years. M. Blanchet's method consists in fixing in the shaft a huge pipe in which is arranged a piston; from this is suspended a cage carrying waggons. By exhausting the air above the piston the load is gradually forced up by the atmospheric pressure below it. The Hottinguer shaft is 660 yards deep, and the pipe is 5 feet 3 inches in diameter, made up of a succession of cylinders of sheet iron about [illegible] inch thick and 4 feet 4 inches high, joined by flanges and bolts. The 485 rings composing the long pipe weigh altogether 418 statute tons. The cage has nine decks, and arrangements are made for unloading three at a time; each waggon holds half a ton, so that the total useful load is 4½ tons. The speed of hoisting is 20 feet per second. If two hoisting pipes are connected the dead weights may be made to balance each other, and the power required is simply that which is necessary to overcome the weight of the useful load. All the men prefer the pneumatic hoist to the ordinary cage for descending and ascending the mine, and are regularly lowered and raised by it. The advantages claimed by M. Blanchet for this system are—(1) the possibility of hoisting from depths at which rope winding would no longer be practicable; (2) getting rid of the costly ropes and dangers connected with rope winding; (3) better utilization of the engine power; (4) improvement of the ventilation and diminution of the amount of fire damp.

10. *Drainage*.—The mineral having been raised to the surface, the task of the miner might appear to be at an end; but this is not the case, for it is further necessary that he should keep his mine free from water and foul air. These two indispensable operations of draining and ventilating frequently require special appliances which add considerably to the general cost of mining.

In all cases where it is possible, endeavours should be made to keep the water out of a mine, so as to save the expense of pumping it; and the method of putting in a watertight lining (*tubbing*) in a shaft has been already described (COAL, vol. vi. p. 62). When large streams of water happen to be intersected by underground workings, and threaten to overpower the available pumping machinery, or when it is advisable to save the expense of draining abandoned workings, the entry of this water into the mine may often be prevented by stoppings called *dams*, constructed of timber or brickwork.

In spite of all precautions, the miner generally has to contend with water which percolates into the workings. Four methods of getting rid of this water are available, viz., adits, siphons, winding machinery, and pumps.

An adit, day level, or sough is a nearly horizontal tunnel with one end opening at the surface, allowing the water to drain away naturally. In hilly countries mines are often worked entirely by adits, and even when a mine is deepened *below the drainage level the utility of the adit is still threefold*;—it lessens the quantity of water which tends to percolate into the lower workings; it lessens the depths to which the water has to be pumped; and, by furnishing a certain amount of fall, it enables water to be applied as power. On account of these important advantages some very *long and costly adits have been driven for the* purpose of aiding the miners in certain metalliferous districts.

Thus in the Harz the Ernest Augustus adit ("Ernst August Stolln") has been driven a distance of nearly 6½ miles into the Klausthal district. The total length of the adit, including the branches, is no less than 14 miles. It intersects many of the lodes at a depth of upwards of 400 yards from the surface. The total cost of this adit is estimated at £8[illegible]000.

Another long adit is the celebrated "Rothschonberger Stolln," which unwaters some of the most important mines at Freiberg in Saxony. The length of the main or trunk adit is more than 8¼ miles; the gradient of the greater part of it is only 1·18 inch in 100 yards. The branches of this adit among the mines are more than 16 miles in length, so that the total length of the main adit with its branches amounts to nearly 25 miles. Many of the mines are now drained naturally to a depth of 250 to 300 yards. The cost of the main tunnel was £359,334, or nearly £24 per yard, but this includes the cost of eight shafts, heavy expenses for pumping from these shafts, the walling of the adit for ¾ mile, and all general expenses. The length of time occupied in driving this adit was thirty-three years. The "Kaiser Josef II. Erbstolln" in Hungary is another remarkable mining tunnel, which was commenced in 1782, and completed in 1878 at a total cost of 4,599,000 florins. It is 10¼ miles in length, extending from the valley of the river Gran to the town of Schemnitz, where it intersects the lodes at depths varying from 300 to 600 yards according to the contour of the surface.

In Cornwall the Great County adit was driven for the purpose of relieving the Gwennap mines of their water, and it was pushed on nearly to Redruth. This adit differs from the great works undertaken in Germany by the fact that it commences in the mining district, and, though the length of all the drivages amounts to more than 30 miles, the water from the most distant mine does not run more than about 6 miles before reaching daylight. The average depth is only 70 or 80 yards from the surface. In fact this great adit, though a work of great utility when the Gwennap district was in a flourishing condition, is merely a network of comparatively shallow drivages, often along the lodes themselves, among the mines, and therefore for boldness of execution cannot for one moment be compared to the great Schemnitz, Freiberg, and Klausthal drainage tunnels which have just been mentioned. The Blackett Level in Northumberland is an adit which has been driven a distance of about 4⅝ miles, and it will have to be extended about 2 miles further before reaching Allenheads. Its depth from the surface at this place will be about 200 yards.

The main part of the Halkyn tunnel in Flintshire is 2 miles 1256 yards in length, and the branch driven out to Rhosesmor mine intersected the vein at a distance of 809 yards, making a total of about 3⅛ miles. The greatest depth from the surface is 230 yards, and the average depth in Halkyn Mountain about

215 yards The length and depth of this adit are not remarkable, but the great quantity of water discharged is a point of considerable interest and importance It is estimated that this adit is now discharging 15 million gallons or 66,000 tons of water in twenty four hours, although the outflow is purely natural, for no mines are pumping water into it It is now easy to understand that the Rhosesmor mine though provided with powerful pumping machinery was unable to cope with the springs it encountered

In the United States the famous Sutro tunnel is an adit of which the main branch, 4 miles in length, reaches the great Comstock lode in Nevada at a depth of 1700 feet The total cost of this tunnel, which was completed in nine years, is estimated to have been $7 000,000 The quantity of water running out daily in 1879 was 12 000 tons at a temperature of 123° Fahr at the mouth of the tunnel All this water must otherwise have been pumped to the surface at a cost estimated at $3000 a day The obstacles to progress were very great not only was the heat extreme, but swelling ground was encountered which snapped the strongest timber Thanks, however to the untiring energy of Mr Adolph Sutro the difficulties were at last successfully overcome, and this great work will long remain as a monument to his foresight, skill, and patient pertinacity

The Atlantic Pacific tunnel [1] which was commenced in 1880, will pierce the heart of the Rocky Mountains under Greys Peak, Colorado It is being driven from both sides of the watershed, and will have a total length of 4⅝ miles from end to end

Siphons Siphons have been used for unwatering workings in special cases, but of course they will not act unless the barrier over which the water is raised is very decidedly less than 33 feet

Winding machinery When workings cannot be drained by tunnels or siphons it is necessary to raise the water mechanically, either to the surface or at all events to an adit through which it can flow away naturally If the amount of water is not too considerable, it is often convenient to use the winding machinery and draw up the water in special buckets (*water barrels*) or tanks The bucket may be tilted over on reaching the surface, or it may be emptied by a valve at the bottom This means of raising water is often adopted while sinking shafts, when it may be desirable to wait till the whole or a portion of the shaft is completed before putting in the final pumping machinery

Pumps The varieties of pumps used in mines are numerous In small sinkings hand pumps, either direct acting or rotary, may be applied, steam jet pumps on the principle of the Giffard injectors are also used, and pulsometers, though requiring a large expenditure of steam, have the advantages of being quickly fixed, of occupying little space, and of working with sandy or muddy water They are capable, therefore, of rendering great services in special cases When we come to the definitive machinery erected in large mines of considerable depth, we find that the prevailing types of pumps are few They may be classified as follows —(A) lifting and force pumps worked by rods in the shaft actuated by wind, water, or steam power, (B) force pumps at the bottom of the shaft worked by steam, compressed air, or hydraulic pressure

A In describing the first method we have to consider the motive power, the rods, and the actual pumps themselves

Windmills have the disadvantage, which is often fatal, that the power is not constant By erecting an auxiliary steam engine which can be set to work if wind fails, this evil is overcome and at the Mona mines in Anglesea a windmill pumps up water from a depth of 80 fathoms at the rate of upwards of 90 gallons per minute As the site of the mine is breezy, there is wind enough to work the mill about one half of the time

Water power was for a long period the principal agent employed in draining mines and it is still of the greatest utility in many districts, reservoirs being constructed to collect and store the rainfall Some idea of the scale upon which these works are conducted will be gathered from the following figures relating to the Harz mines In 1868 there were ' sixty seven reservoirs covering an area of 604 acres and having a storage capacity of 336,000,000 cubic feet [2] The total length of the various leats, races, and other water courses, including the six principal adits, is about 170 statute miles The net power extracted is reckoned at 1870 horse power, but less than one fourth of this is used for pumping

Water power is applied to pumping machinery by water wheels, turbines, and rotary or non rotary water pressure engines Excepting the case of the latter, the rotary motion has to be converted into a reciprocating motion by a crank, and furthermore with turbines the speed must be reduced very considerably by intermediate gearing

Overshot wheels are the commonest prime movers when pumps are worked by water power, water wheels are frequently constructed 40 or 50 feet in diameter, and at the Great Laxey mine, in the Isle of Man, one of the wheels is no less than 72 feet 6 inches in diameter and 6 feet in the breast The power is conveyed from the water wheel by a connecting rod to a bell crank (*bob*) placed over the shaft, and when, owing to the contour of the ground, the wheel has to be placed at a distance, it is connected to the bob by the so called *flat*

ater pressure engines have the advantage c

to utilize any amount of fall, and those which are direct acting can be applied immediately to the main rod of the pumps

Steam, however, is the power used *par excellence* in draining mines, indeed the first applications of steam power were made for this purpose and Watt s great inventions owed their birth to the necessities of mines which could no longer be drained by the water power at their command

Cornish engine. The principal type of engine is that known as the Cornish engine, which is a single acting condensing beam engine working expansively Its mode of action may be briefly described as follows The steam is let in at the top of the cylinder and presses down the piston, which is connected with one end of a large beam, whilst the main rod of the pumps is attached to the other When the piston has completed its course the equilibrium valve is opened by a cataract, and the pressure on both sides of the piston being now equal, the weight of the pump rods, or rather the excess of their weight over that of the counterbalances causes them to drop and force up the water from the mine by means of the plungers, which will be described immediately Double acting rotary engines working the pumps by cranks may also be met with

The rod in the shaft, known as the *main rod* or *spear rod*, is usually made of strong balks of timber butted together and connected by *strapping plates* fastened by bolts It serves to work either lifting pumps or force pumps, or both

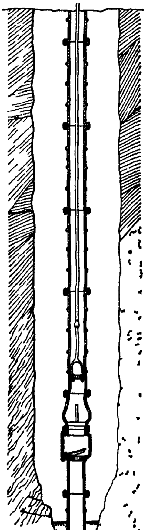


Fig 87

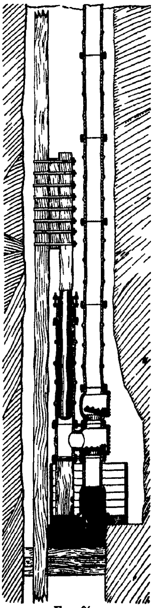


Fig 88

The lifting pump, or drawing lift (fig 87),[3] consists of the wind bore, the clack piece, the clack seat piece, the working barrel surmounted by pumps, and the bucket with its rod The whole works like any ordinary pump, and needs no special explanation

---

[1] *Mining and Scientific Press*, San Francisco, 1882, vol xlv p 241

[2] "Notes on the new Deep Adit in the Upper Harz Mines," by H Bauerman, *Report of the Miners Association of Cornwall and Devonshire*, 1868, p 21

[3] Michell and Letcher on "Cornish Mine Drainage,' *Forty Third Annual Report of the Royal Cornwall Polytechnic Society*, p 211.

The force pump used in mines, known as the plunger pump, consists of a solid piston (*plunger*) (fig 88)[1] working through a stuffing box in a pump standing on the H piece This has a valve which communicates with the *windbore* resting in the cistern Above the H piece comes the *door piece* with another valve, and then a series of pipes, generally of cast iron, but occasionally of wrought iron, constituting the column The upward motion of the plunger, which is attached to the main rod, causes an inflow of water, which is forced into the column when the plunger descends It is usual to fix a drawing lift at the bottom of the shaft, which raises the water into a first cistern, and thence a plunger forces it into a second cistern some 60 yards higher up, and it is continually forced up from cistern to cistern until it reaches the adit or the surface

There are numerous important matters which require special attention, such as the valves, catches, balance bobs, guiding arrangements for the rod in inclined shafts, the V bobs fend off bobs, and running loops, which have to be used when there are bends in the shaft but space will not permit of more than mere mention of these details

Such then is the standard arrangement worked by steam or water power for pumping from mines The great advantage of the system consists in the employment of the plunger, because it is simply necessary for the machine to raise a weight slightly greater than that of the water, which is forced up afterwards by the down stroke of the rods Leaks are readily discovered, and the stuffing box can be easily screwed up as the packing wears this is one great reason of the superiority of the plunger compared with a piston working in a barrel

The modifications of this system relate more to the engines employed than to the actual pumps themselves

The cylinder of the Cornish engine is sometimes reversed and stands over the shaft, the main rod being attached directly to the piston This type of engine, known as the Bull engine in Cornwall dispenses with the ponderous beam, but it has the great disadvantage of obstructing the mouth of the shaft The use of two cylinders combined, as invented by Woolf, causes less strain upon the main rod and pumps (*pit work*) and machinery generally as the initial velocity of the piston is smaller and the engine starts with less jerk The cylinders are placed side by side or one above the other

Kley's engines

Kley of Bonn, has constructed engines on the Woolf system with steam acting on both sides of the pistons He makes the excess of the weight of the rod over that of the counterbalances sufficient to raise only half the weight of the water and to overcome the friction and then in the descending stroke the steam acts on the top of the piston and so makes up for the insufficiency in force of the rods As the steam acts on both sides of the piston the same amount is consumed it is true, but a smaller cylinder will do the work and the original cost of the engine is lessened The same engineer of late years has put up several pumping engines in Belgium Germany and France of 30 to 560 horse power, with a fly wheel which serves simply to regulate the stroke of the piston so that the crank always stops before or after the dead point till the cataract starts another stroke The engines are double acting, with two cylinders and beam The advantage of working with the fly wheel is that the main rod and pumps are set in motion without the injurious jerk unavoidable with a Cornish engine worked at a high rate of expansion

Guinotte's engine

M Guinotte, the well known Belgian engineer also adopts a fly wheel, and the engines he has erected at Mariemont and elsewhere are single acting rotary engines with one cylinder The peculiarity of the fly wheel is that he can weight it in any way he pleases, and he so overcomes the difficulty which occurs in other rotary machines, of its being impossible to work them below a certain speed His object has been to make the speed slow at the beginning and end of a stroke, so as to avoid the injurious shocks to the valves and machinery generally from sudden starts and stoppages In order to make the main rod act by traction only and not compression which may be advisable with iron rods, the plungers are sometimes reversed, whilst Kraft of Seraing has introduced the Rittinger pump, which consists of a hollow moving plunger with a valve inside and a plunger case above it working over a hollow fixed plunger By this arrangement both the up and the down stroke of the engine cause water to be forced up, and this pump is used with a double acting rotary engine

B We must now speak of the second class of pumps viz force pumps worked by steam, water power, or compressed air at the bottom of the shaft

The steam pumps are of very various descriptions[2] but they mostly consist of one or two plungers, or rams set in motion by a rotary or a non rotary engine, which may or may not work with expansion and condensation The plunger or ram is generally fixed directly on to the piston, and works in the same line, consequently the power is transmitted to the plunger with the least possible loss The water is forced up the shaft in one long column Engines and pumps of this kind are easily kept in order, all the parts are readily accessible The miner is able to dispense with the heavy beam, the massive engine house, the long main rod and its connexions and bobs, the various cisterns and plungers, and instead he has a compact and easily supervised machine and a simple line of pipes taking up but little space in the shaft, the pump can therefore be erected and set to work very quickly, and this is a matter of the utmost importance in emergencies It is true that these direct acting steam pumps, even when worked by a compound engine, cause a greater consumption of coal than the Cornish engine, but, as a set off, there is the economy in first cost, erection, and repairs which has led to their adoption more especially in collieries The steam is generated by boilers underground, or is conveyed from the surface in well jacketed pipes

If natural water power is available water pressure engines working the plunger directly are often employed, and indeed such water power may be created artificially for use in workings where steam power is objectionable on account of the heat There are other reasons too for employing water for transmitting power, where the length of the rods is very great, and they have to be worked quickly, there is a great liability to breakages, in order to overcome these difficulties at the mines on the Comstock lode, Mr Joseph Moore[3] uses a steam engine at the surface to work an hydraulic accumulator, and then by pipes conveys the water under pressure to hydraulic engines working plungers These are fixed at 2400 feet from the surface, and force the water in one column, 813 feet high, to the level of the Sutro tunnel The exhaust water is returned to the surface in pipes and used over again The pumps are now raising 1600 to 1700 gallons per minute

Where compressed air is being supplied to a mine for drilling and winding purposes, it is often convenient to employ it, by means of direct acting pumps, such as are generally used with steam, for the drainage of small temporary sinkings and occasionally large pumps raising considerable quantities of water are worked in this way

11 *Ventilation and Lighting*—The composition of the air of the atmosphere is about one fifth by volume of oxygen and four fifths of nitrogen, with a little carbonic acid gas, more exactly, the standard amount of oxygen may be taken at 20 9 per cent, and that of the carbonic acid gas at 0 03 per cent The atmosphere of mines is subject to various deteriorating influences not only do noxious gases escape from the rocks into the underground excavations, but also the very agents employed in the execution of the work itself pollute the air considerably

Deleterious gases

The dangerous emanations of fire damp in collieries have been already described (COAL, vol vi p 72), and with reference to this gas it is simply necessary to say that its presence is not entirely confined to coal mines Large quantities have been observed in Silver Islet mine,[4] Lake Superior, where several explosions have occurred, whilst small quantities are met with in the stratified ironstone of Cleveland, and also in the Cheshire salt mines, jets of the gas may be seen constantly burning in the salt mine at Bex in Switzerland, a little has been noticed also in lead mines in Wales and Derbyshire In the Sicilian mines the amount given off by the black carbonaceous shales interstratified with the sulphur beds is sufficient to cause dangerous explosions It has been pointed out (vol vi p 72) that carbonic acid gas exudes from coal,[5] it escapes also from some mineral veins At the lead mines of Pontgibaud in central France it is so abundant that special fans have to be provided for getting rid of it, very distinct issues of this gas may be observed at the Foxdale mines in the Isle of Man, and in the Alston Moor district it is not uncommon This gas is likewise given off in the Sicilian sulphur mines, where also the highly poisonous sulphuretted hydrogen is of frequent occurrence, the water in the workings being often saturated with it Small quantities of mercurial vapour occur in quicksilver mines

---

[1] Michell and Letcher on 'Cornish Mine Drainage, *Forty Third Annual Report of the Royal Cornwall Polytechnic Society*, p 211.

[2] Stephen Michell, *Mine Drainage*, London, 1881

[3] *Trans Inst Engineers and Shipbuilders in Scotland* 1882

[4] *Engineering and Mining Journal*, vol xxxiv p 522

[5] A Schondorff, "Untersuchung der ausziehenden Wetterstrome in den Steinkohlenbergwerken des Saarbeckens, *Zeitschrift fur das Berg, Hutten, und Salinen Wesen im Preussischen Staate* vol xxiv p 73, and Cl Winkler, "Die chemische Untersuchung der bei verschiedenen Steinkohlengruben Sachsens ausziehenden Wetterstrome und ihre Ergebnisse,' *Jahrbuch für das Berg und Huttenwesen im Konigreiche Sachsen auf das Jahr* 1882, p 65

Products of respiration, blasting &c. Such then are the principal gases which naturally pollute the atmosphere of mines, and have to be swept out by ventilation In addition to these we have the products of the respiration of the men and animals in the pit, and those due to the combustion of candles or lamps, and the explosion of gunpowder, dynamite, &c

Dr Angus Smith[1] reckons that two men working eight hours, and using ½ lb of candles and 12 oz of gunpowder, produce 25 392 cubic feet of carbonic acid (anhydride) at 70° F,—viz, 10 32 by breathing 12 276 by candles, and 2 796 by gunpowder

The products of the explosion of gunpowder have been carefully studied by Captain Noble and Sir Frederick Abel, and the following figures, showing proportions by weight, are copied from the valuable paper containing the results of some of their researches —

	Curtis & Harvey's No 6 Gunpowder	Mining Powder
Total solid products	57 74	47 04
Total gaseous products	41 09	51 35
Water	1 17	1 61
	100 00	100 00

34 46
2 08
2 40 | 2 [illegible]
3 [illegible]6 | 5 [illegible]4

The volume (calculated for a temperature of 0° C and barometer 760 mm of mercury) of permanent gases generated by the explosion of 1 gramme of dry powder is—

MM Sarrau and Vieille have communicated to the Academy of Sciences[3] the results of their researches concerning the decomposition of certain explosives and more particularly gun cotton and nitrated gun cotton The following table shows in litres, the volume at 0° C and 760 mm of mercury) of each of the gases per kilogramme of the substance exploded in a closed vessel —

(60 per cent) [illegible]
Nitro glycerin [illegible]
Ordinary blasting powder 64 150

Kind of Explosive	NO_2	CO	CO	H	N	CH_4	Total
Pure gun cotton	139	237	104	45	[illegible]3	7	565
Gun cotton and nitrate of potash (50 per cent of each)	1	[illegible]	[illegible]	3	7		1[illegible]6
Gun cotton (4[illegible] per cent) and nitrate of ammonia (6[illegible] per cent)	12[illegible]	6	10[illegible]	1[illegible]	11		414
Nitro glycerin	21[illegible]	16[illegible]	[illegible]	[illegible]	[illegible]	1	4[illegible]2

When explosives are decomposed in this way they liberate nitric oxide and carbonic oxide, and the analyses of MM Sarrau and Vieille confirm the practical experience of miners, who complain greatly of noxious fumes when, owing perhaps to a bad detonator, a charge of dynamite or tonite fails to explode properly

The air of mines is finally deteriorated by organic matter contained in the exhalations of the men and animals employed and in the products of decaying timber, by dust, and by the solid particles constituting the smoke of explosives It must be recollected also that the injury to the air is not confined to the addition of the gases and substances just mentioned, but the proportion of oxygen is diminished by the combustion of candles, by respiration, the decay of timber, and decomposition of some minerals such as iron pyrites Dr Angus Smith[4] sums up the results of his analyses of the air of British metal mines as follows —

		Percentage by volume.
Oxygen	average of [illegible]39 specimens	20 26
,,	of ends	20 18
	other parts	20 32
,,	in currents	20 65
	in large cavities	20 77
,,	just under shafts	20 42
,,	in sumps	20 14
Carbonic acid		0 785

He considers air with 20 9 per cent oxygen as normal, and air with proportions between that and 20 6 as impure, and where the percentage of oxygen descends below 20 6 he calls the air exceedingly bad According to these standards, only 10 67 per cent of the samples showed the air to be normal or nearly so, 24 69 per cent were decidedly impure, whilst 64 63 per cent or nearly two thirds of the samples were exceedingly bad The amount of oxygen in one specimen was as low as 18 52 per cent, whilst the carbonic acid often exceeded 1 per cent and in several instances 2 per cent It is evident that twenty years ago the ventilation of British metal mines was anything but satisfactory, and even now there is room for improvement

Having explained the reasons why the air of mines must be constantly renewed, we must now point out how this desirable end is effected

Systems of ventilation. Two systems are employed,—natural ventilation and artificial ventilation, but, as both systems have been described (COAL, vol vi p 70), little remains to be said here, especially as the ventilating machines in metalliferous mines generally cannot for one moment be compared with the powerful appliances employed in collieries In vein-mining there are generally many more shafts than in collieries, and natural currents are set up which are often considered sufficient for ventilating the mines, nevertheless, the advanced workings, such as the ends, rises, and winzes,—in fact all workings in the form of a *cul de-sac*,—are likely to require special means of ventilation as soon as they proceed a little distance from the main air current

The means of ventilating a drift or heading are various. If a natural or artificial draught exists at the mouth of the drift, it may be diverted by an upright partition (*brattice*), or an air way may be constructed along the roof or floor by a horizontal partition of planks (*air sollar*) (fig 89) In this way a sufficient supply is secured at the end or fore breast

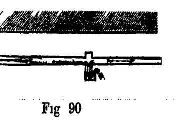


Fig 89

The water blast is another simple appliance, it is precisely the same as the well known tromp, and it blows a current of air through square pipes made of boards, or better through cylindrical pipes of sheet zinc

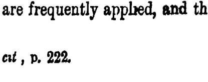


Fig 90

The fall of water may be applied by Williams's water-jet, shown in fig 90 The jet of water acts like an injector, and creates a powerful current

Small fans driven by boys, or better by small water-wheels or other machinery, are frequently applied, and the

---

[1] *Report of the Commissioners Appointed to Inquire into the Condition of all Mines in Great Britain to which the Provisions of the Act 23 & 24 Vict c 151 do not apply*, Appendix B, p 224

[2] "On Fired Gunpowder, Captain Noble and Mr F A Abel, *Phil Trans*, 1880, p 278

[3] "Recherches experimentales sur la decomposition de quelques explosifs en vase clos, composition de gaz formes *Comptes Rendus*, 1880, pp 1058 and 1112

[4] *Op cit*, p. 222.

Harz blower (*duck machine*, Cornwall) (fig 91) is not uncommon. This is merely an air pump of very simple construction which is worked by the main rod of the pumps, and can be arranged so as to exhaust the foul air or force in fresh air.

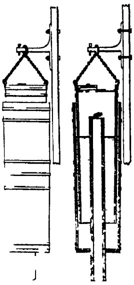


Fig 91

In working in blasting ground, boring machines driven by compressed air are becoming more and more largely used every day, and the exhaust air escaping from the machines is invaluable for ventilation. At the same time, on account of volley firing, the quantities of deleterious gases generated in a short space of time are very considerable, and, in order to get rid of them speedily, the compressed air may be utilized for working a Korting aspirator or the somewhat similar ventilator of Mr Teague, a jet of compressed air turned into a ventilating pipe, which creates an exhaust (fig 92[1]). Naturally this ventilator is merely brought into play at the time of blasting, and while the boring machinery is out of use. When compressed air is being supplied on a large scale to a mine for boring and winding machinery, it is often convenient to convey it by a small gas pipe to working places in which the ventilation is inadequate. Of course, in one sense, it is very uneconomical to compress air to a pressure of 60 or 70 ℔ to the square inch for ventilating purposes only; but, where compressing machinery is always at work on the mine, it may be better to be a little wasteful of cheap power at the surface than to go to the greater expense of having a man or boy to work a fan underground.

Aspirators

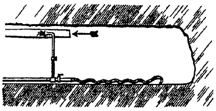


Fig 92

Lighting

Mines are lighted by lamps, torches, candles, and electricity. The subject of safety lamps for fiery mines has already been discussed (see COAL, vol vi p 72), and consequently the question of illuminating mines may be treated in a very summary manner.

Lamps vary very much in shape and size. The Sicilian miner has a mere shallow cup of unglazed pottery; the Saxon a small tin or brass lamp in a wooden box lined with tinplate and open in front. In the Harz the miner prefers a heavy flat iron lamp with a hook by which it is stuck into the timber or any crack in the rocks; in France, northern Italy, and parts of Spain, the iron lamp is lenticular in shape and also suspended by a hook. In Scotland, and parts of Germany and the United States, a small tin lamp of the shape shown in fig 93 is very common; the hook enables it to be carried on the hat while climbing ladders, and to be fixed up underground. Olive oil and rape oil are burnt in these lamps; petroleum lamps are employed occasionally.

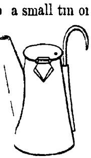


Fig 93

The miners of England and Wales still cling to the tallow candle, and when surrounded by a lump of clay it can easily and quickly be fixed in the working place or carried upon the hat when climbing. Gas brought down from the surface answers for illuminating large excavations, such as on setting places and engine rooms.

Up to the present time the electric light has been but little used underground on account of its want of portability, and the smallness of the spaces requiring illumination. Very often a few men only are employed in each working place, and consequently the expense incurred in fixing and shifting the lamps and maintaining them alight would be out of proportion to the value of the work executed. However, an incandescent electric lamp has been invented weighing only 10 ℔, which gives the light of three candles for six hours, and it may be reasonably expected that improvements will be made which will render the electric light more available for underground purposes than it is at present. When the area requiring illumination is large, an arc lamp may be used with advantage. Among the first successful applications of electric lighting to underground excavations may be mentioned that of M Blavier at the Angers slate quarries. In the year 1879 he fixed two Serrin lamps in one of the large underground chambers with an area of 2400 square yards, and he found that they gave light enough for all the men at work. The total cost, reckoning everything, viz., coal, carbons, repairs, labour, depreciation of plant, and interest on capital, is 50 francs per day; the gas formerly in use cost 54 francs a day and gave much less light. It is evident, however, that the arc lights can only be applied with advantage in special cases where a large number of men are concentrated in one working area which can be illuminated from one or two points.

The large chambers in the salt mine of Maros Ujvar in Hungary have been regularly lighted up by electricity since 1880. The cost is somewhat greater than that of the tallow, oil or petroleum formerly in use; but, on the other hand, the illumination is better, the men can do more work and are more easily supervised, whilst the air of the mine is not deteriorated by the products of combustion of the lamps.[3]

Means of access

12. *Means of Descending into and Ascending from Mines.*—Where mines are worked by adit levels the men naturally walk in along the ordinary roadways; such mines, however, are exceptional, and the men generally have to climb down and up by ladders, or are raised and lowered by machinery. The means of access to and from workings may be classified as follows:—(1) steps and slides; (2) ladders; (3) cages; (4) man engines.

Steps.

If a lode or seam is inclined at an angle of 40° or 50° from the horizon steps may be cut in the floors of the deposit if it is firm enough, or wooden steps may be put in with a hand rail. Even with higher dips steps may be arranged by directing them in a line intermediate between the dip and the strike. In speaking of conveyance underground, reference has already been made to the practice of carrying sulphur ore in Sicily and slate in Germany up to the surface by steps; and steps may be found in other foreign mines and occasionally in Great Britain. They are much less fatiguing than ladders placed so flat that part of the weight of the body rests upon the arms. In some of the Austrian salt mines the men descend by wooden slides inclined at angles varying from [illegible] to 50°, flattening at the bottom to destroy the velocity gradually; the ascent is effected by steps.

Slides

Ladders.

Ladders are very largely used in metal mines all over the world, but they vary a good deal in different countries. The ladder consists of two sides and a series of rungs (*staves*, Cornwall). The sides are usually made of wood, and the rungs of wood or iron. The distance between the rungs is important; 10 inches from centre to centre is sufficient, for climbing upon ladders with the rungs 12 inches apart is decidedly more fatiguing. On the Continent wooden rungs are commoner than iron ones, and oak is preferred. Sometimes the wooden staves, instead of being round, are flat, so as to stand more wear, and iron sides may be seen in places where dry rot is very bad. Platforms should be fixed at short intervals, not exceeding 3 or 4 fathoms in perpendicular shafts, so as to prevent falls from having fatal consequences.

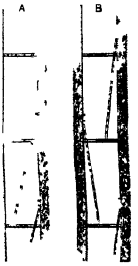


Fig 94

In many cases sufficient attention is not paid to the angle of inclination of the ladders. A ladder is climbed with the least fatigue when the person uses his arms simply to steady himself, and is not compelled to pull himself up by them, as on a vertical ladder, or to support much of the weight of his body by them, as happens with a very flat one. The best angle is about 20° from the vertical, and in Belgium the authorities have very wisely decreed that no ladder shall be inclined at an angle of less that 10° from the vertical. Furthermore, of the two arrangements shown in fig 94

---

[1] *Trans Roy Geol Soc Cornwall*, vol x p. 142.

[2] M Blavier, "L'Éclairage électrique aux Ardoisières d'Angers," *Annales des Mines*, ser 7, vol xviii, 1880, p 5.

[3] *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, 1882, No. 25, p 296.

A is better than B, because it not only affords a greater inclination for the ladders, but also renders it less likely that a man will drop through the opening (*manhole*) in the platform (*sollar*) if he loses his hold and falls. These may seem trifling matters; but, leaving aside the question of safety, the economy derived from fixing the ladders at the best inclination is by no means small. To make this apparent we must recollect the depths to and from which men have to climb, viz., 300, 400, and even 500 yards. It is important, therefore, to save every unnecessary expenditure of energy, which, though trifling for one ladder, becomes considerable when repeated a great number of times. When a mine has reached a depth of 200 yards, and *a fortiori* when it exceeds it, mechanical appliances should be introduced for raising and lowering the men, because time and strength are wasted by climbing. Medical men also are agreed that excessive ladder climbing is injurious to the health of the miner. Therefore, both upon hygienic and financial grounds, one of the first thoughts in working a mine should be the conveyance of the men up and down the shafts by machinery with the least possible fatigue.

Cages

In collieries and other mines worked by perpendicular shafts, it has long been customary to raise and lower the men by the ordinary winding machinery already described. In the United Kingdom it is necessary that guides should be used if the shaft exceeds 50 yards in depth; safety catches and disengaging hooks (COAL, vol. vi. p. 75) are frequently applied for the purpose of preventing accidents. The simplicity of this method of ingress and egress naturally renders it popular, and statistics prove that, where proper precautions are used, it is exceedingly safe.

Man engines

The first man engine was put up in the Harz in 1833, and nine years later a similar machine was fixed in Tresavean mine in Cornwall. Since that time this very useful means of conveying workmen up and down shafts has been resorted to in other mining districts, and especially in Belgium and Westphalia.

Two kinds of man engine are in use: the double rod machine and the single rod machine. The double rod or original man engine consists of two reciprocating rods like the main rods of pumps, carrying small platforms upon which the men stand. The stroke is from 4 to 16 feet, and the little platforms are so arranged that they are always opposite each other at the beginning and end of each stroke.

Figs. 95 and 96 represent the rods in the two final positions. A man who wishes to descend steps upon platform *b* (fig. 95); the rod *B* goes down and A goes up, so that *b* (fig. 96) is brought opposite *c*. The man steps across from *b* to *c*, and then the rod A makes a down stroke, B an up stroke. Platform *c* is now opposite *d* (fig. 95), and the man again steps across; and thus by constantly stepping from the rod as it completes its down stroke the man is gradually conveyed to the bottom of the shaft. By reversing the process, or, in other words, by stepping off on to the opposite platform as soon as the rod has completed its up stroke, the man is raised to the surface without any fatigue beyond that of the very slight effort of stepping sideways. If each rod makes four up and down strokes of 10 feet each per minute, the rate of ascent or descent will be 80 feet per minute.

Fig. 95.

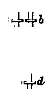


Fig. 96.

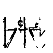


Fig. 97.

The single rod man engine has one rod carrying steps, whilst fixed platforms are arranged in the shaft so as to correspond exactly with them (fig. 97). If a man wants to go down, he steps on to A when the up stroke is completed; the rod goes down and A is brought down opposite to the fixed platform *b*, on to which he steps off. He then waits on *b* until the rod has finished its up stroke. C is brought opposite *b*; he steps on to B, the rod goes down and he is brought opposite *c*, where he steps off again and waits. By reversing the operation he is gradually lifted to the top of the shaft. The single rod engine may be used by men going up while others are going down, provided that there is sufficient room upon the fixed platforms (*sollars*). The best plan is to have sollars right and left as shown in the figure, and then the ascending men step off to the left, for instance, while the descending men take the right hand sollars. The ascending man steps on to the man engine as soon as the descending man steps off, and so the rod may be always carrying men up or down. The usual stroke in Cornwall is 12 feet, and there are from three to five or six strokes a minute. With five strokes the men descend 10 fathoms a minute, or in other words a descent or ascent of 300 fathoms occupies half an hour. The reciprocating motion is best obtained from a crank, because in this case the speed is diminished gradually at the dead points, and the danger of an accident in stepping off and on is thereby diminished; man engines, however, are sometimes driven by direct acting engines.

Man engine rods are constructed of wood or iron, and at Andreasberg in the Harz each rod is replaced by two wire ropes. Like a pump rod the man engine rod requires proper balance bobs and catches, and for the safety of the men a handle is provided at a convenient height above each step.

The man engine has one great advantage over the cage, which consists in the fact that it can be safely applied in inclined and even crooked shafts; and it is for this reason that man engines have been adopted in many metal mines unprovided with vertical shafts.

Careful comparisons as regards safety of travelling have been made in Prussia between ladders, man engines and cages. The average accidental death rate is shown by the accompanying table, which gives averages for a period of ten years, 1871 to 1880:—

	Ladders	Man engines	Cages
Average annual number of men travelling	8 942	7 191	64 071
Total number of persons killed	5	41	74
Average annual death rate per 1000	0 101	0 570	0 115

The table shows that the cage is nearly as safe as ladders. In reality, if the actual distance travelled were taken into account, the cage would appear to be safer, because we may fairly assume that the mines in which men are hoisted by cages are on the whole very much deeper than those in which men ascend and descend by ladders. The man engine appears to be decidedly more dangerous than either the cage or ladders. Here again a distinction requires to be made between the single rod and the double rod machines, and the Prussian statistics include many of the latter. It will be readily understood that a fall in a naked shaft with few fixed platforms is much more likely to be fatal than a fall in the shaft of a single rod man engine which is closed with the exception of the manhole at intervals of 12 feet. The Belgian *warocquères* are rendered safer than the Harz or Saxon man engines by having a railing round the back of each platform on the rod. Some of the double rod machines are made with large platforms so that two persons can stand on them, one going up and the other going down, or both travelling in the same direction. The use of double rod man engines has been entirely abandoned in the United Kingdom. The death rate from accidents on man engines in Cornwall and Devon during the nine years 1873 to 1881 was 0 17 per 1000 persons using them, whilst the annual death rate per 1000 persons using ladders was slightly higher, viz., 0 19. If the actual distance travelled were taken into account, the scale would turn more decidedly in favour of the man engine.

The cost of raising and lowering men by the man engine is not great. At Dolcoath, a tin mine in Cornwall approaching 400 fathoms in depth (see figs. 62, 63), it is reckoned that 1½d. per man per day covers all expenses, including interest upon the capital expended and depreciation of plant.

Dressing of ores.

13. *Dressing or Mechanical Preparation of Ores.*—In a large number of cases the mineral, as it is raised from the mine, is not ready for sale. It usually requires to be subjected to mechanical processes whereby the good ore is entirely or partly freed from valueless veinstone. These processes, which in a few special instances are aided by calcination in furnaces, are known as the dressing or mechanical preparation of the ores. As a rule the valuable ore is specifically heavier than the veinstone, and most of the separating processes are based upon the fact that the heavy particles of ore will fall in water more quickly than the light particles of veinstone.

The processes of mechanical preparation may be classified as follows:—(1) washing and hand sorting; (2) disintegration, or reduction in size; (3) classification by size or by equivalence; (4) concentration.

(1) Sometimes the ore coming from the mine requires simply to be freed from adhering particles of clay in order

to be rendered fit for sale, at other times the washing is necessary as a preliminary process previous to sorting by hand The operation is performed either by raking the ore backwards and forwards upon a grating under a stream of water, or in a box containing water, or, thirdly, by means of an inclined revolving iron drum worked by hand or any other motive power The machines used for this purpose, known as washing trommels, are revolving cylinders or truncated cones of sheet iron provided with teeth inside The ore is fed in at one end, is subjected to the action of a stream of water, and is discharged at the other end

The *stuff*, *i e*, the mixed ore, veinstone, and country rock, having been cleansed, it is now possible to make a separation by hand Women and children are generally employed for this work, as their labour is cheaper and their sight sharper than that of men The stuff is spread out on a table, and various classes are picked out according to the nature of the products furnished by the mine Thus in a lead mine we may have—(*a*) clean galena, (*b*) mixed ore, *i e*, pieces consisting partly of galena and partly of barren veinstone, (*c*) barren veinstone and country rock This is a most simple case, very frequently we have to deal with a vein producing ores of two metals, especially in the case of lead and zinc, and then the classification into various qualities becomes more complicated

Disintegration

(2) Reduction in size is necessary for two reasons Even when an ore is sufficiently clean for the smelter the large lumps are often crushed by the miner for the sake of obtaining a fair sample of the whole, or supplying a product which is at once fit for the furnace The chief reason, however, for disintegration lies in the fact that the particles of ore are generally found enclosed in or adhering to particles of barren veinstone

The disintegration is effected by hand or by machinery Large blocks of ore and veinstone are broken by men with large sledge hammers, and the reduction in size is continued very often by women with smaller hammers Sometimes the blow of the hammer is directed so as to separate the good from the poorer parts, and hand picking accompanies this process, called *cobbing* Ore may be crushed fine by a flat headed hammer (*bucking iron*) on an iron plate

The machines used for reducing ores to smaller sizes are very numerous here it is impossible to do more than briefly call attention to those most commonly used These are stone breakers, stamps, rolls, mills, and centrifugal pulverizers

Stone breaker

The stone breaker, or rock breaker is a machine with two jaws, one of which is made to approach the other and so crack any stone which lies between them The best known stone breaker is the machine invented by Blake, which has rendered inestimable services to the miner for the last twenty years, and the introduction of which constituted a most important step in advance in the art of ore dressing Its mode of action is very simple When the shaft A (fig 98) revolves, an excentric raises the "pitman" B, and this, by means of the toggle plates C, C, causes the movable jaw D to approach the fixed jaw E by about $\frac{3}{8}$ inch at the bottom When the pitman descends the jaw is drawn back by an india rubber spring The jaws are usually fluted, the ridges of one jaw being opposite the grooves of the other, and they are so constructed that the wearing parts are quickly and easily replaced

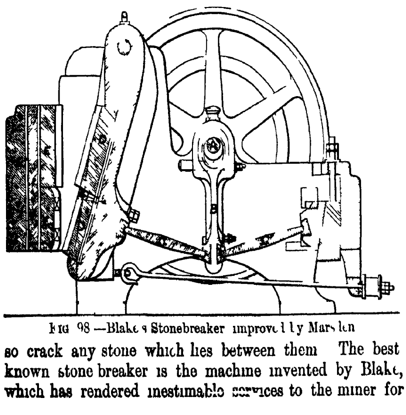


FIG 98 —Blake's Stonebreaker improved by Marsden

Mr Marsden of Leeds has lately introduced a pulverizer, constructed on the principle of the stone breaker which will reduce large stones to the finest powder in one operation The moving jaw has an up and down as well as the old backwards and forwards motion, and the stones are first cracked and then ground by the double action

Stamps.

Stamps are pestles and mortars worked by machinery The construction of the modern California stamp mill with revolving heads is explained in GOLD, vol x p 747, and the description need not be repeated In Cornwall the older form with rectangular heads still prevails

It is impossible to give any correct average figures representing the work done by a stamping mill, because this varies with the hardness of the stuff treated and the fineness to which it must be reduced However, it is usual in Cornwall to reckon 1 ton of tinstuff and in California 1 to 1¼ ton of gold quartz stamped per horse power in twenty four hours

Stamps are principally used in dressing the ores of gold, silver, and tin, but are occasionally employed for those of copper and lead The stamps described at vol x p 747 act simply by gravity Another form, which has met with favour in the Lake Superior district, is the direct acting or Ball stamp, which works like a steam hammer, the blow of the head being assisted by the pressure of steam At the Calumet and Hecla Mill Lake Superior each Ball stamp is capable of crushing 130 tons in twenty four hours In a third kind of stamps, the heads are lifted by a crank and the power of the up stroke compresses a cushion of air (pneumatic stamps) or a spring, storing up power which makes the down stroke strike a heavier blow

Rolls.

Revolving rolls were introduced in the west of England in the early part of the present century to replace *bucking* by hand The machine, now often known as the Cornish crusher, consists of two cast iron or steel cylinders which revolve towards each other whilst at the same time they are kept pressed together by levers or springs The cylinders or rolls are generally from 18 inches to 2 feet or 2 feet 8 inches in diameter and 12 to 22 inches wide

Mills.

Stone mills constructed like flour mills are employed in some countries for reducing ores to powder, and the *arrastra*, which consists of heavy stones dragged round upon a stone bed, has rendered good service in grinding and amalgamating gold and silver ores, in spite of its being slow and cumbersome Edge runners (Chilian mills) also deserve mention

Iron mills known as *pans*, with grinding surfaces made of chilled cast iron and arranged so that they can be quickly and easily replaced when worn out are greatly in vogue in the United States for the treatment of ores of gold and silver, the ore delivered to them is already finely divided and they are intended not only still further to reduce the size of the particles but also and more especially to effect the amalgamation of the precious metals with quicksilver The pulverizers used in Cornwall for grinding grains of tin ore with a little waste still adhering to them are also iron mills

The centrifugal pulverizers are machines by which the

Centrifugal pulverizers.

pieces of ore are thrown with great velocity against bars or arms, or against each other, and so reduced to powder; in other machines iron balls or iron rollers are whirled by centrifugal force against an iron casing and grind any mineral contained inside it. These pulverizers are much less used than stone breakers, stamps, and rolls for the disintegration of metallic ores.

sif- n of s

(3) Classification of a crushed ore into sizes is absolutely necessary in some cases and advisable in others, because the subsequent concentration is dependent upon the fall of the particles in water, as will be presently explained. Classification by size is effected by sieves. Hand sieves and flat sieves placed one above the other have been superseded at most dressing establishments by cylindrical or conical revolving screens known as trommels. These screens are made of wire web or of perforated sheets of metal, and they are often arranged so as to discharge one into the other, so that the ore from a crusher can quickly be separated into classes of various sizes.

With sizes of less than 1 millimetre ($\frac{1}{25}$ inch) trommels are no longer employed, and recourse is had to the so called separators or classifiers. These are boxes in the shape of inverted cones or pyramids into which the finely crushed ore is brought by means of a current of water; a jet of clean water is often made to rise up in the bottom; the larger and the specifically heavier particles fall and are discharged with a stream of water at or near the bottom, whilst the smaller and specifically lighter particles flow away at the top. The separators do not effect a true classification by size; they merely cause a division by *equivalence*, a term which will be explained immediately.

(4) We now have to deal with the enriching of the ore, or the concentration of the valuable particles into as small a bulk as is economically advantageous. The concentration is generally brought about by the fall of the particles in water. Occasionally the fall in air is utilized; mercury is employed as a collecting agent in the case of gold and silver, and in a few instances magnetism can be applied.

The concentration in water depends upon the difference in specific gravity of the valuable ore and the waste veinstone or rock. A piece of galena with a specific gravity of 7.5 sinks to the bottom more quickly than a similar piece of quartz, the density of which is only 2.6. Nevertheless a large piece of quartz may fall to the bottom as quickly as a small piece of galena. Particles which have equal velocities of fall, though differing in size and specific gravity, are said to be *equal-falling*, or *equivalent*. P. von Rittinger shows that a sphere of quartz of $\frac{1}{4}$ inch in diameter would sink in water exactly as quickly as a sphere of galena of $\frac{1}{16}$ inch in diameter, and these two particles are therefore equal-falling. Consequently, before we can separate properly by water it is necessary to classify the particles by size, so that equivalence shall not prevent a separation or lessen its sharpness. It is nevertheless true that in the early part of the fall of equivalent grains the influence of the specific gravity preponderates, and the denser particles take the lead; therefore, by a frequent repetition of very small falls, particles which have not been closely sized may still be separated.

The principal machine for concentrating particles of sizes ranging between 1 inch and $\frac{1}{50}$ inch is the jig or jigger. The hand jigger is merely a round sieve which is charged with the crushed ore and then moved up and down in a tub full of water. The particles gradually arrange themselves in layers, the heaviest on the bottom and the lightest at the top. On lifting out the sieve the light waste can be skimmed off with a scraper, leaving the concentrated product below ready for the smelter or for further treatment. Similar sieves worked by machinery were for a long time employed in dressing establishments, but the introduction of the improved continuous jiggers has led to their abandonment in all works of any importance. The continuous jigger is one of the most useful dressing machines of the present day. It consists of a box or hutch divided by a partial partition into two compartments; in one is fixed a flat sieve *s* (fig. 99), which carries the ore, and in the other a piston *p* is made to work up and down by means of an eccentric. The hutch being full of water, the movement of the piston causes the water to rise up and fall down through the ore, lifting it and letting it fall repeatedly. The effect of these frequent lifts and falls is to cause a separation of the previously sized ore into layers of rich mineral at the bottom, light waste at the top, and particles of ore mixed with waste in the middle.

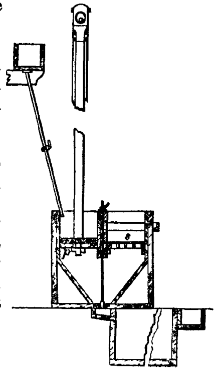


Fig. 99

The great value of these jiggers is the continuous discharge of the products without stoppages for their removal. Several methods are in vogue, viz., the end discharge, the central discharge and the discharge through the meshes of the sieve. With the first, the enriched product lying at the bottom of the sieve passes out through openings at the end of the jigger, and the amount escaping is governed by an adjustable cap or shutter, by which the size of the openings can be increased or diminished at pleasure; the middle product can be discharged by openings placed a little higher up, whilst the waste is washed over the top of the end of the jigger at each pulsation. Very often a first sieve simply separates a concentrated product and discharges the poorer product into a second sieve, where a similar separation is effected. With the central discharge, a pipe is brought up through the bottom of the sieve, and the size of the opening for the escape of the concentrated ore is regulated by a cylindrical cap which can be raised or lowered by a screw. The discharge through the sieve is especially adapted for the finer products from the crusher, though it is also used in some cases for grains up to $\frac{1}{4}$ inch in diameter. The mesh of the sieve is chosen so that the particles under treatment will just pass through, but above the sieve a layer of clean ore is placed which prevents anything but the heavier particles from being discharged. The pulsations of the water, as before, cause a separation into layers, and the heavy rich particles find their way through the bed and drop into the hutch whence they can be drawn off through a hole at pleasure. The poorer part passes over a simple sill at the end of the sieve, or to a second sieve if necessary. Three or four sieves are occasionally arranged in a row in one machine.

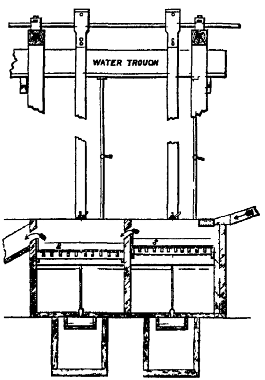


Fig. 100

Fig. 100 is a section through the two sieves of a Harz sand jig. The pistons act in the manner explained by fig. 99.

The smaller sizes are concentrated by a variety of machines. The action of many of them is based upon the behaviour of particles carried down an inclined plane by a thin stream of water. If the gradient of the plane and the strength of the thin current are properly arranged, the denser particles will be deposited and the specifically lighter ones washed away, although they may be *equal-falling* if allowed to settle in deep water.

The principal machines for concentrating fine sands and slimes are the frame, rotating frame, percussion frame, side blow percussion frame, revolving belt and Frue vanner, the hand buddle, the round buddle, and the keeve

The frame is simply an inclined wooden table upon which a thin deposit is formed by the sheet of ore and waste bearing water which is made to flow over it gently The stream is then stopped and the deposit washed off by hand or automatically, and collected in pits for subsequent retreatment by similar appliances if necessary

The rotating frame is a round table with a very flat convex conical surface the ore in suspension flows on at one part of the centre and forms a thin deposit which is richest at the top and poorest at the bottom and this deposit is washed off so as to form two classes by means of jets of water under which the table passes as it turns round Concave rotating tables fed at the circumference, are also employed

The percussion frame, the *Stossheerd* of the Germans is a table [illegible] blow it bumps against a piece of timber before receiving the next blow These bumps cause the ore to settle and after a thick deposit is formed it is dug off with the shovel the upper end being richer than the middle or the tail

Rittinger's side blow percussion frame is a suspended rectangular table ABCD (fig 101), receiving blows and bumps on the side and not on the end A stream of orey water S is fed on at the corner A clean water W is supplied by the other head boards H H H and the table is pushed out by cams in the direction of the arrow and is driven back by a spring so that the cross piece F strikes against a bumping block K The light particles travel down the table much faster than the heavy ones and take a comparatively straight course, whereas the heavy and richer particles remain on the table subject to the influence of the side blows for a much longer time and travelling along a curved path reach the bottom at F The middle class is discharged at G and the poor waste at K The exact degree of richness of the products can be regulated by altering the point as strips of wood which can be turned so as to divide the stream of ore and waste where thought most desirable The great advantage of this machine over the old percussion frame is its continuous action

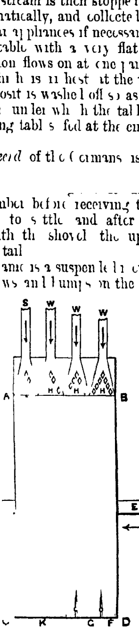


Fig 101

Frue vanner The Frue vanner (fig 102) may be looked upon as an improved form of Brunton's simple revolving belt It is an endless band of india rubber cloth flanged on each side, which revolves slowly in the direction of the arrows whilst at the same time it is shaken sideways by a crank motion The orey water is fed on at A, clean water at B The natural path of the particles is down the inclined belt but the specifically heavier ones settle upon it and are carried upwards Those that can resist the action of the stream of clean water at B go over the end and are washed off as the belt passes through the tank The poor stuff falls into the waste launder The degree of concentration can be regulated by the slope and speed of the belt and the strength of the streams of ore and water The Frue vanner has the disadvantage that it makes only two classes rich and poor without any intermediate product

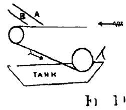
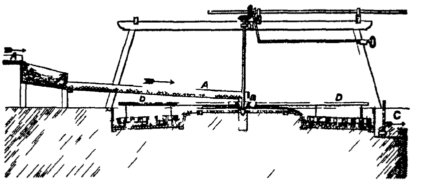


Fig 102

Buddles The hand buddle is a rectangular wooden box with a sloping bottom A stream of fine ore and waste suspended in water is fed in at the upper end and gradually forms a deposit on the bed of the buddle A boy with a broom keeps the top of the sediment smooth, so as to ensure regularity of action After a thick deposit has accumulated it is dug out in sections which decrease in richness from the upper end (*head*) to the lower end (*tail*)

Round buddles like rotating frames, are of two kinds convex and concave The convex round buddle (figs 103[1] and 104) is a circular pit with a truncated cone or head, of varying size in the centre and a bottom sloping towards the circumference The orey stream A falling over this head runs down gently, depositing the heaviest particles near the top, the lighter ones further down, whilst the lightest of all flow away at C The surface of the sediment is kept even by revolving brushes D This machine may be compared to



a number of hand buddles arranged radially round a centre The deposit that is formed is dug out in rings of varying richness

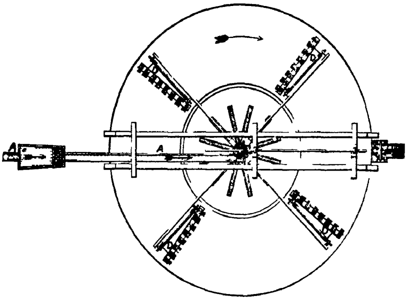


Fig 104

The concave buddle is a circular pit with a [illegible] sloping towards the centre The stream of ore is fed all round the circumference and runs inwards to the middle where the lightest particles escape The rich head is of course near the circumference

The keeve is a large tub in which the fine stuff is stirred with water and then is allowed to settle from a state of suspension whilst blows are being struck on the side of the tub The deposit is afterwards scraped out in layers which increase in richness as they approach the bottom

The series of processes employed in dressing an ore varies, not only according to the nature of the particular mineral to be concentrated, but also according to the size of its particles and the nature of the other minerals with which it is associated

With gold the reduction in size is usually effected by stone breakers and stamps, and much of the metal is then caught by mercury what escapes is concentrated with its accompanying pyrites by inclined tables covered with blankets, or by buddles and the concentrate is treated by amalgamation or chlorination See GOLD vol x p 746

In the case of silver the ore is frequently pulverized by stamps, and the resulting *pulp* amalgamated in pans or barrels The ore may also be concentrated by any of the various machines described, and delivered to the smelter Many of the ores of silver are sent to the smelting works without any concentration by water, as this would cause a serious loss

Lead ore is generally crushed by rolls, often after a preliminary reduction in size by the stone breaker The crushed ore is classified by revolving screens down to the size of 1 mm, and the resulting grains concentrated by jigging, *dredge*, or grains of ore and matrix [illegible] be recrushed, sized, and jigged The finer sizes are classified by pyramidal boxes and concentrated by frames rotating tables, and buddles

Zinc ore is dressed in the same way as lead ore and as galena and zinc blende are frequently intimately associated together, it is necessary to separate them by the use of the jig, buddle, and frame

---

[1] Henry T Ferguson, "On the Mechanical Appliances Used for Dressing Tin and Copper Ores in Cornwall" *Proc Inst Mech Eng*, 1878 pl 41.

Tin bearing rock is crushed by the stone breaker and then stamped fine The resulting sand and slime may be concentrated by the repeated use of the round buddle, with the keeve for a final cleaning, but often the sand only is enriched by the buddle, whilst the very finest particles, constituting an almost impalpable mud (*slime*) when mixed with water, are treated by frames When much pyrites is present it is necessary to make a preliminary concentration and roast the enriched product (*witts*) in a furnace The calcination converts the heavy iron and arsenical pyrites into a light oxide which can be got rid of with the rest of the waste by buddling and framing The final product from the keeve is clean enough to approach pure cassiterite in the percentage of metal Alluvial tin ore is concentrated in *sluice boxes*, and sometimes by jiggers, after a preliminary treatment in a *puddling machine* (GOLD, vol x p 745) if there are balls of clay which have to be broken up When the alluvial ore occurs as a hard conglomerate (*cement*), it has to be stamped

Copper Copper ores are treated by crushing by rolls and sometimes stamps sizing by trommels, and then jigging and buddling but, as some of the ores are very friable and easily carried away by water, hand picking is employed to a greater extent than with lead and tin ore, and the enrichment by water is not carried so far on account of the inevitable loss that would ensue The amount of concentration depends upon the distance from the smelting works, and the mine owner has to calculate whether it is best to get a low price for a large quantity of ore after paying the carriage, or a higher price for a smaller lot (*parcel*) when due allowance has been made for the cost of dressing and loss sustained in that process Thus for instance in Cornwall, the ore containing copper pyrites is dressed so as to contain only from 5 to 8 or 9 per cent of metal because it can easily be conveyed to Swansea by sea and because further reduction in bulk would cause greater loss in value than the saving of freight

Loss in dressing The loss in dressing is very considerable P von Rittinger estimates it at from 30 to 50 per cent, and stubborn facts bear out his conclusions Heaps of refuse from dressing floors are frequently worked over again with profit and in the year 1881 no less than 909 tons of ' black tin (*i e* concentrated tin ore fit for the smelter), worth £35 283 were extracted from the muddy water allowed to flow away from the dressing floors of some of the principal Cornish tin mines

The fall in air has been employed instead of the fall in water for concentrating purposes and several ingenious air jigs have been constructed and worked upon this principle

Separation by magnetism In exceptional cases magnetic attraction may be utilized Magnetic iron can be separated in this way and the magnetic process is applied for treating mixed blende and chalybite the specific gravities of which are too close to render concentration by water practicable The mixed ore is calcined and the chalybite is thus converted into magnetic iron which can be extracted by a magnetic separator leaving saleable blende

Recent improvements Before concluding this part of the subject we will briefly enumerate the principal improvements that have been made in metal mining during the last quarter of a century They are as follows —diamond drill for prospecting, machine drills for driving sinking, and stoping, use of compressed air for winding underground, stronger explosives, especially the nitro glycerin compounds dynamite and blasting gelatin increased use of steel for various purposes, Blake s stone breaker and continuous jiggers, extended application of hydraulic mining larger employment of electricity both for blasting purposes and for signalling by telegraph and telephone It may be reasonably hoped that ere long electricity will render increased services to the miner for lighting the workings and for the transmission of power

14 *Recent Legislation affecting Mines in the United Kingdom* [1]—In England the person owning the surface of a freehold is *prima facie* entitled to all the minerals underneath, excepting in the case of mines of gold and silver, which belong to the crown The crown, however, does not claim gold and silver extracted from the ores of the baser metals The ownership of the minerals can be, and often is, severed from that of the surface, the latter being sold whilst the mineral rights are reserved by the original owner Local customs, now regulated by Acts of Parliament, are still in force in Derbyshire (High Peak Mining Customs and Mineral Courts Act, 1851, 14 & 15 Vict c 94, and the Derbyshire Mining Customs and Mineral Courts Act, 1852, 15 & 16 Vict c 43) and in the Forest of Dean (1 & 2 Vict c 43, and 24 & 25 Vict c 40) The Stannaries Act (32 & 33 Vict c 19) regulates the commercial dealings of mining companies in Cornwall and Devon, and provides for their liquidation

The working of mines in the United Kingdom is controlled by five Acts of Parliament, viz, "The Coal Mines Regulation Act, 1872 (35 & 36 Vict c 76), "The Metalliferous Mines Regulation Acts, 1872 and 1877" (35 & 36 Vict c 77, and 38 & 39 Vict c 39), "The Stratified Ironstone Mines (Gunpowder) Act, 1881' (44 & 45 Vict c 26), and "The Slate Mines (Gunpowder) Act, 1882" (45 Vict c 3) The last three Acts simply refer to the annual returns, and exemptions from certain restrictions concerning the use of gunpowder

The Coal Mines Regulation Act applies to mines of coal stratified ironstone shale and fire clay The Metalliferous Mines Regulation Act applies to all mines not included under the Coal Mines Act, and therefore controls not only workings for lead tin copper, and iron commonly known as mines but also the salt mines and underground quarries worked for stone slate or other earthy minerals The principal provisions of the Coal Mines Regulation Act have been set forth at vol vi p 78 those of the Metalliferous Mines Regulation Act are similar but less strict owing to the almost complete absence of fire damp One important difference is that the manager of a mine under the Metalliferous Act need not hold any certificate of competency or service

Other Acts of Parliament are the Explosives Act 1875 (38 Vict c 17) regulating the manner in which explosives are stored, the Elementary Education Acts 1876 and 1880 (38 & 39 Vict c 79 and 43 & 44 Vict c 23) regulating the employment of children the Factory and Workshop Act 1878 (41 Vict c 16), which applies to the dressing floors of mines under the Metalliferous Mines Regulation Act

The statute of Elizabeth (43 Eliz c 2) which was passed for raising money for the relief of the poor mentions coal mines, but omits other mines these have been made subject to poor rates by The Rating Act 1874 (37 & 38 Vict c 54) The ' Employers Liability Act 1880 (43 & 44 Vict c 42) extends and regulates the liability of employers to make compensation for personal injuries suffered by workmen in their service Finally, if as sometimes happens works are put up at a mine for roasting copper ores with common salt in order to extract the metal by the wet way the provisions of the Alkali &c Works Regulation Act 1881 (44 & 45 Vict c 37), must be attended to

It is thus very evident that the laws affecting mines have received most important additions during the last few years

Accidents 15 *Accidents in Mines* —Mining is one of the occupations that may decidedly be called hazardous This fact has been thoroughly impressed upon the public mind by explosions of fire damp in collieries, but, though accidents of this kind are appalling, owing to the number of victims who perish at one time, fire damp is by no means the worst enemy with which the miner has to contend Falls of roof and sides both in collieries and metal mines are far more fatal in their results With the risks attending the collier s calling we need not deal, as statistics upon this subject have been already given (see COAL, vol vi p 79), but the figures below relating to metalliferous mines prove that the occupation of the metal miner is very little less dangerous

---

[1] For information concerning the laws relating to mines in the United Kingdom, see W Bainbridge *A Treatise on the Law of Mines and Minerals*, 1878 and Arundel Rogers *The Law relating to Mines, Minerals, and Quarries in Great Britain and Ireland, with a Summary of the Laws of Foreign States*, 1876

Mines classed under the Metalliferous Mines Regulation Act in Great Britain and Ireland

	Persons Employed.			Number of Deaths from Accidents						Death rate from Accidents per 1000 persons employed		
				Under Ground				Above Ground	General Total			
	Under Ground	Above Ground	Total	Falls of Ground	In Shafts	Miscellaneous	Total			Under Ground	Above Ground	Under Ground and Above Ground
1874	34,036	22 325	56 361	40	34	15	89	14	103	2 61	0 62	1 82
1875	34,905	23 168	58 073	32	35	33	100	19	119	2 86	0 82	2 05
1876	34 109	23 388	57 497	25	16	23	64	6	70	1 87	0 25	1 21
1877	34 095	23 300	57 395	41	21	24	86	11	97	2 52	0 47	1 69
1878	30 624	20 834	51 458	27	19	23	69	8	77	2 25	0 38	1 49
1879	28 265	18 795	47 060	24	16	16	56	8	64	1 98	0 42	1 36
1880	32 045	20 863	52 908	31	21	19	71	13	84	2 21	0 62	1 59
1881	33 291	21 651	54 942	36	22	32	90	9	99	2 70	0 41	1 80
1882	33,814	21 692	55 [illegible]06	30	27	17	74	18	92	2 18	0 83	1 65
Total and averages for the nine years	295 184	196 016	491 200	286	211	202	699	106	805	2 37	0 54	1 63

This table[1] shows that the average accidental mortality of the persons employed *underground* in metalliferous mines is 2 37 per 1000 During the ten years 1873–1882 the corresponding mortality at mines under the Coal Mines Act was 2 57, showing a difference of only 0 20 per 1000 in favour of the metal miner, and when we take the well known metalliferous district of Cornwall and Devon we find a death rate for the ten years mentioned of 2 63 per 1000, which therefore exceeds that of coal mines

Reference to the table shows that more than one third of the deaths were caused by falls of ground The actual percentages of the deaths are as follows —falls of ground 35 , in shafts 26 2 miscellaneous 25 1, on surface 13 1 The accidents in shafts are due to falls from ladders cages and man engines, ropes and chains breaking, overwinding and other causes, whilst the miscellaneous accidents include numerous fatalities in connexion with blasting operations The surface accidents are mostly caused by persons becoming entangled in machinery, and there have been several fatal boiler explosions

In spite however, of all the dangers to which miners are exposed they are less likely to be the victims of accident than railway servants, among whom the rate of fatal accidents varies from 2 5 per 1000 on passenger traffic lines to 3 5 per 1000 on lines possessing a heavy goods traffic

Statistics concerning accidents in mines are published by many foreign countries the most minute are those prepared by the Government mining engineers in Prussia The average annual death rates per 1000 persons employed below ground and above ground from accidents in mines in Prussia during the fifteen years 1867 to 1881 have been —coal mines 2 952 lignite mines 2 474 metal mines 1 446, other mines 1 693, all the mines together 2 476 In making any comparison between these figures and those we have given for Great Britain, it is necessary to recollect that the mines under the Coal Mines Act include some workings which in Prussia would be classed as metalliferous and that British mines under the Metalliferous Act include underground stone quarries

Before concluding the subject of accidents it is necessary to point out that successful efforts have been made of late years to mitigate their results In the first place persons equipped with the Fleuss breathing apparatus can now enter mines after explosions in spite of the noxious and irrespirable gases and save lives which would otherwise be sacrificed[3] Secondly by means of the instruction afforded by classes established by the St John Ambulance Association miners are learning how best to render first aid to the injured before the arrival of a medical man and there is no doubt that many valuable lives have been lost in times past for want of this knowledge Thirdly a vast amount of good has been done by the establishment of Miners Permanent Relief Societies in different districts which afford aid to persons disabled by accidents and to the dependent relatives of those who have unfortunately lost their lives by any mining fatality

16 *Useful Minerals produced in Various Parts of the Globe*

Great Britain and Ireland —The mineral produce of the United Kingdom for the year 1881 is summ[illegible] Robert Hunt[4] is

Minerals	Quantities		Values		
	Tons	cwts	£	s	d
Coal	154 184 300	0	65 528 327	10	0
Iron ore	17 446 065	6	6 201 068	6	6
Tin ore	12 898	3	697 444	5	3
Copper ore	52 556	1	190 057	8	7
Lead ore	64 702	5	656 725	0	0
Zinc ore	35 527	7	110 043	10	8
Iron pyrites	43,616	14	30 033	6	5
Gold ore		1¼	18	0	0
Silver ore	5	19	358	7	0
Cobalt and nickel ore	63	14	809	12	8
Manganese	2 884	0	6 441	5	0
Wolfram	54	7	544	1	9
Ochre and umber	7 936	9	12 286	7	0
Arsenic	6 156	8	45 070	7	6
Fluor spar &c	[illegible]	14	2 [illegible]3	10	0
Clays	2 401 421	0	1 200 210	0	0
Salt	2 298 2[illegible]0	0	1 149 110	0	0
Barytes	21 313	11	23 894	3	10
Sundry minerals including coprolites gypsum calc spar shales &c			49 500	0	0

The total value of minerals produced in 1881 was £76,201,695, 2s, exclusive of slate, building stone, limestone, and other stones worked by mines and quarries

The quantity of coal raised in 1882 was 156,499 977 tons

The metals obtained from the ores produced in the United Kingdom in 1881 were—

Metals		Quantities	Values
			£
Gold	ounces	4¼	15
Silver from ore		1 6[illegible]0	360
Silver from lead		[illegible]08 398	[illegible] 140
Pig iron	tons	8 144 449	20 361 122
Tin		8 615	839 680
Copper		3 975	263 500
Lead		48 567	728 805
Zinc		14 947	25[illegible] 606
Other metals estimated			1 [illegible]
Total value of metals produced in 1881			£ [illegible] 514 50[illegible]

The total value of minerals and metals obtained from the mines and other mineral workings of the United Kingdom in 1881 was—

81 652

£ 80 860 4[illegible]7

From these tables it is evident that coal and iron are by far the most important mineral productions of the United Kingdom as 94 per cent of the total value is due to these two substances

France —The mineral productions of France[5] for the year 1880 are set forth in the following table —

	Quantities	Values
	Metric Tons	Francs
Mineral fuel	19 [illegible]2 000	24[illegible]
Peat	248 000	[illegible]
Asphalt rock and bituminous shale	144 000	[illegible]
Iron ore	2[illegible] 4 000	14 [illegible]
Iron pyrites and sulphur	1 [illegible] 000	[illegible] 114 000
Metallic ores	[illegible] 000	[illegible]
Rock salt	3[illegible] 000	11 [illegible]
Brine salt	[illegible]	[illegible]
General totals	14 [illegible]00	2[illegible] 711 000

---

[1] From *Reports of H M Inspectors of Mines for the year* 1882 p xxxvi

[2] *The Rate of Fatal and Non Fatal Accidents in and about Mines and on Railways, with the Cost of Insurance against such Accidents* by Francis G P Neison, London, 1880

[3] *Reports of H M Inspectors of Mines for the year* 1881 Mr Bell s Report p 463

[4] *Mineral Statistics of the United Kingdom* for 1881, p ix

[5] *Statistique de l Industrie Minerale et des Appareils à Vapeur en France et en Algérie*, Année 1880 Paris, 1882, p 45

The quantities of metal produced in France from native and foreign [illegible] in 1880[1] were—

Pig iron		Nickel	30 metric tons
[illegible]		Gold	31 kilogrammes
Copper		Silver	40 400 ,,
		Aluminium	1 1[illegible]0

[illegible] mining industry of the German empire is of high importance The output of the mines in 1881 is shown by the following table,—taken from the *Stat Jahrb fur das Deutsche Reich*, Berlin, 1883, p 27 The production of common salt, potassium chloride, and other salts from brine is also considerable. The total quantity for the German empire in 1881 was 693,000 metric tons, worth 33,567,000 marks, including 113,200 tons of potassium chloride valued at 14 090,000 marks

	Coal	Lignite	Rock Salt	Potash Salts	Iron Ore	Zinc Ore	Lead Ore	Copper Ore	Silver and Gold Ore	Iron Pyrites and other Vitriol and Alum Ores	Other Mining Products	Total Value of all the Mining Products
	Unit 1000 Metric Tons	Unit 1000 Metric Tons	Unit 1000 Metric Tons	Unit 1000 Metric Tons	Unit 1000 Metric Tons	Unit 1000 Metric Tons	Unit 1000 Metric Tons	Unit 1000 Metric Tons	Unit 1000 Metric Tons	Unit 1000 Metric Tons	Unit 1000 Metric Tons	Unit 1000 Marks
Prussia[2]	[illegible]	1 41[illegible]	20[illegible] 8	[illegible]4[illegible] 4	3906 3	6[illegible]9 2	1[illegible]	[illegible]	0 1	142 0	[illegible]3[illegible]	3[illegible] 42[illegible]
Bavaria	[illegible]	1[illegible] 1	0 9		7[illegible]		0 8	0 [illegible]		1 1	1[illegible]	124
Saxony[4]	0 [illegible]	60			23 8		1	0 1	2[illegible] 7	0 1	1 2	[illegible] 7
Wurtemberg			84 2		1[illegible] 3					0 1		[illegible]
Baden	[illegible]4					0 3					0 0[3]	110
Hesse		30 [illegible]			13[illegible] 8						0 6	1 11[illegible]
Mecklenburg		12 [illegible]										46
Thuringia	[illegible]	[illegible] 3			28 4			0 0[3]		0 4	1 4	1 [illegible]
Brunswick		2[illegible] 7			96 4		0 [illegible]				18 0	1 [illegible]8
Anhalt		[illegible]6 1	1[illegible] 0	360 5			1 4				2 1	6 344
Schaumburg-Lippe	1[illegible]9											9[illegible]
Waldeck					32 [illegible]						0 0[3]	1[illegible]0
Alsace-Lorraine	[illegible]	[illegible] 2			10[illegible] 0		0 3			2 4	9 7	6 [illegible]90
German empire	4[illegible]	1[illegible] 3	311 9	90[illegible] 9	5411 [illegible]	6[illegible]9 [illegible]	164 8	523 7	26 8	14[illegible] 1	67 7	384 000
Luxemburg					2161 [illegible]							4 994
Total	1[illegible]88 [illegible]	1[illegible] 3	311 9	90[illegible] [illegible]	[illegible] 3 8	[illegible]	164 8	23 7	26 8	146 1	6[illegible] 7	3[illegible]8 994

Austria-Hungary—Among the famous mines of the Austria-Hungarian empire may be mentioned those of Hungary and Transylvania for gold and silver Styria produces much of the iron quicksilver is yielded by the mines of [illegible] in Carniola, lead and silver by those of Przibram in Bohemia salt is obtained in the Austrian Alps and in Galicia, which also produces petroleum and [illegible]

The production of minerals and metals in Austria[5] during the year 1881 was as follows —

1[illegible]		— [illegible]	
Quic[illegible]		— [illegible]	[illegible]
Copper		— [illegible]	481
		— [illegible]	[illegible]
		— [illegible]	[illegible]
		— [illegible]	[illegible]
		—Metallic zinc	4 11[illegible]

C[illegible]

F[illegible] value of the produce of the Austrian mines in 1881 was 44 6[illegible]3 6[illegible]2 florins The total output of salt in 1881 was 2[illegible] 27[illegible] metric tons valued according to the monopoly prices at 2[illegible]000 498 florins

Hungary in 1879[6] produced

Gold	1[illegible] kilogrammes	Iron	11[illegible]3[illegible]1 metric tons
Silver	1[illegible]	Coal	[illegible]4[illegible]8
Copper	1[illegible] metric tons	Lignite	[illegible]
[illegible]	1[illegible]	Iron pyrites	[illegible]

M[illegible]

Belgium—Belgium is rich in coal, the output in 1881 being no less than 16 87[illegible] 9[illegible]1 metric tons valued at 163 704 242 francs Though it produces iron ores it is largely dependent upon other countries and especially the grand duchy of Luxemburg for supplies for its blast furnaces The principal lead mine is that of Bleiberg and the calamine deposits in the neutral territory of Moresnet have long been worked with success by the celebrated Vieille Montagne Company which also owns zinc mines in Belgium, Germany, Sweden Sardinia, and Algeria

Russia—In a vast empire like Russia it is not surprising that there should be valuable deposits of a great variety of minerals Among the most important are the auriferous alluvia of the Ural mountains and Siberia which in 1880 yielded 115 940 troy lb of gold worth more than [illegible] millions sterling Platinum is found associated with the gold-bearing sands of the Urals the output in 1880 was 7[illegible]95 troy lb Zinc ore is largely worked in Poland Important supplies of chrome iron ore are derived from the Urals, amounting in 1880 to more than 8000 tons The metallic copper produced in 1880 was about 3100 tons and the oil wells of Baku yielded in that year 346 000 tons of petroleum Russia also possesses mines of iron ore manganese lead, silver, coal, and lignite A little tin ore is furnished by Finland

Italy—The most important mineral in Italy[7] is sulphur, 35[illegible],540 tons (metric), worth 36,448,453 lire, having been obtained in 1880, and mainly from seams containing the native element in the Miocene rocks of Sicily and Romagna

The celebrated iron mines of the island of Elba have been worked from very early times and furnish a valuable ore and the deposits of calamine lead ore and silver ore in Sardinia form no small proportion of the mineral wealth of the Italian kingdom The gold mines in and near the Val Anzasca (Piedmont) are producing more than 7000 ounces of metal yearly

Spain—Spain is justly celebrated for its mineral wealth It produces more cupreous pyrites than any other country in the world, and very large amounts of lead ore and quicksilver and its iron ores are abundant and of excellent quality The principal lead mines are in the provinces of Jaen (Andalusia) and Murcia and the total amount of metallic lead produced in Spain or from Spanish ores is estimated to be 120,000 tons yearly

Cinnabar, the heavy red ore of mercury, naturally attracted attention at a very early date, and the world renowned Almaden mine has been worked from time immemorial The output in 1880 was 1387½ tons (metric) of quicksilver[8]

The cupreous pyrites, often known as sulphur ore is obtained from the province of Huelva, where vast deposits occur over a belt of country nearly 100 miles long by 20 miles wide The Rio Tinto mines are the largest in the district, and are worked on a gigantic scale The company employs upwards of 10 000 hands or more persons than are engaged in all the Cleveland iron mines and the output is upwards of a million tons per annum About one quarter of this containing 3½ per cent of copper is exported, mainly for the manufacture of sulphuric acid and subsequent treatment for copper and silver, whilst the remaining three quarters, with 2⅓ to 2½ per cent of copper, are treated on the spot The ore contains rather less than 1 oz of silver to the ton and a few grains of gold These are profitably extracted from the burnt ore by Claudet's process, and some idea of the importance of the copper and silver will be gained by reference to the following figures[9] During the year 1881 there were obtained from cupreous pyrites imported into the United Kingdom in 1881, mainly from Spain and Portugal, 14,0[illegible]0 tons of copper, 258,463 oz of silver and 1490 oz of gold The total value of the silver and gold was £64,195

The total output of iron ore in 1880 was 3,565 338 metric tons,[10] more than two thirds, viz, 2[illegible]83 627 tons being obtained from the celebrated mines near Bilbao in the province of Biscay England, France, Belgium, and Germany are all glad to draw supplies of excellent red and brown hæmatite from the Bilbao mines Murcia comes next in importance to Biscay, with a production of 539,328 tons

---

[1] *Stati[illegible]que d[illegible] l Industrie [illegible]* *Algerie* An[illegible] 1880 [illegible]

[2] Detailed statistics concerning the mi[illegible] of Prussia are [illegible] every year in the *Zeitschrift fur das Berg- Hutt[illegible]* *Staate* (Berlin)

[3] Quantity less than [illegible]0 tons

[4] Detailed statistics of the mineral produce of Saxony [illegible] in the *Jahrbuch fur das Berg und Huttenwesen [illegible] Konigreiche Sachse* (Freiberg)

[5] *Stat Jahrb des k k Ackerbau Ministeriums fur* 1881 Heft [illegible] Lief 1, Vienna 188[illegible]

[6] Der B[illegible]rgwerksbetrieb Ungarns im Jahre 1879 *Oesterreichische Zeitschrift fur Berg und Huttenwesen*, 1881 p [illegible]71

[7] *Notizie statistiche sulla Industria M[illegible]* *in Italia dal* 18[illegible]0 *al* 1880 Rome, 1881 p 40[illegible]

[8] *Estadistica Mi[illegible]* *de España correspondiente al año de* 1880 Madrid, 1882, [illegible]

[9] Hunt *Mineral Statistics* &c p 45

[10] *Estadistica Minera*, &c *ut supra* p 15

Portugal —The great mineral belt of Huelva extends into Portugal, and deposits of cupreous pyrites almost identical with that of Rio Tinto have been wrought from very early ages The principal mine, San Domingos, is close to the Spanish frontier It is estimated that the workings had yielded up to the year 1877 no less than 3,578,74[illegible] English tons of cupreous pyrites, by far the greater part of this having been extracted in recent times The quantity of ore raised from the mine in 1882 was 405 029 tons

Portugal possesses notable manganese mines, but produces comparatively small quantities of iron, lead, and copper

Norway —The mines at Kongsberg are famous for the large quantities of native silver they produce, and enormous masses are sometimes met with The annual output is from 10,000 to 12,000 troy ounces Copper ore and cupreous pyrites are also mined in Norway, and there are important workings for nickel and cobalt and for apatite Alluvial gravels have been washed for gold in Norwegian Finland

Sweden —The most important mineral obtained in Sweden is iron ore, much being in the form of magnetite red hæmatite also is mined, and brown hæmatite is dredged up from some of the lakes The principal iron-producing districts are those of Norberg, Dannemora, Nora, and Persberg The output of the Swedish mines in 1880 was—

Iron ore	775 [illegible]20 tons	Zinc ore	43 45[illegible] tons
Lead ore	12 [illegible]88	Copper ore	[illegible] 560

Greece —One of the most interesting undertakings of modern times has been the re-working of the Laurium mines which are situated in the southern extremity of Attica, and an account of them written by Cordella furnishes many curious details concerning the methods of mining, washing, and smelting employed by the ancients The workings for lead and silver appear to have been carried on with the greatest vigour between 600 B C and the Peloponnesian War, and were finally abandoned in the 1st century of the Christian era Huge piles of slag which had accumulated from the old smelting works were found to be well worth being re-worked for silver and lead, and operations were commenced in 1864 Five years later the old heaps of mine refuse began to be treated and at last in 1875 a French company resumed working the mine A Greek company employing some 3000 persons is now producing annually from the old mine heaps no less than 8000 to 9000 tons of pig lead, yielding 45 oz of silver to the ton, whilst the mines of the *Compagnie française des mines du Laurium* made an output in 1881 of [illegible],664 tons (metric) of roasted calamine, with 40 to 60 per cent of zinc in addition to lead ore and mixed ores Cordella calculates that during the three hundred years the Laurium mines were worked by the ancients the total amount of lead produced was 2,100,000 tons, with 22½ million troy ℔ of silver Besides this the ancients left behind two million tons of lead slags containing on an average 10 67 per cent of lead, 109 million tons of mine refuse with 1½ to 18 per cent of lead, and excavations to the extent of 51 million cubic yards with lead ore still in sight They did not touch the calamine deposits [1] Next in importance to lead silver and zinc comes bay salt and after that emery The island of Naxos furnished 3300 metric tons of emery in 1877 valued at £28 000

Africa —Algeria is rich in iron and three-fourths of the value of its total mineral output are due to ores of this metal In 1880 the iron mines produced 614 000 metric tons of ore, Mokta el hadid mine, near Bona, alone yielding about 300,000 tons Algeria also possesses mines of copper lead, zinc and antimony

The name "Gold Coast applied to part of the shores of Africa, denotes its productiveness of the precious metal, and it is probable that very important supplies of gold will one day be derived from various districts of the Dark Continent

Cape Colony possesses rich copper mines in the Namaqualand division, which in 1882 produced ore and metal worth £[illegible]31 [illegible]46 however, the most valuable and remarkable mineral deposits of Africa at the present time are the diamond mines The first diamonds were obtained from recent gravel in the bed of the Vaal river, and it was afterwards discovered that the precious stones could be obtained from the so called dry diggings The most important of these, the Colesberg Kopje, now known as the Kimberley mine, produced in 1881 diamonds weighing 900,000 carats, worth £1,575,000 Three other neighbouring mines are Old De Beers, which yielded 300,000 carats in 1881, worth £600,000, Du Toit's Pan, and Bulfontein The value of the diamonds raised in South Africa since 1870 amounts to forty millions sterling, indeed the Kimberley mine alone was estimated in 1877 to have already produced ten million pounds worth of diamonds, extracted from 4 million tons of diamantiferous rock

Asia —For many centuries India was regarded as possessing fabulous mineral wealth, and a strong basis for this idea may be found in the existence of traces of mining on a very extensive scale No doubt in early days India did supply what then appeared to be very large quantities of metals, and a country that produces gold and precious stones is apt to be endowed by the popular mind with boundless riches The actual amounts of mineral raised in India at the present day are comparatively small Gold exists over considerable areas, but it remains to be proved that the gold mines of the Wynaad and Mysore can be profitably worked by British companies Diamonds occur and are worked in alluvial diggings and in a conglomerate belonging to the Vindhyan formation Sapphires and rubies are obtained from Upper Burmah Ceylon[3] produced in 1880 no less than 10,286 tons of graphite or plumbago, valued at £192,879 Petroleum is abundant in Upper Burmah, and oil from wells has been utilized for upwards of twenty centuries The total output in 1873 was estimated to be about 10,000 tons yearly Tin ore occurs and is worked in Tenasserim Passing into Siam and the Malay Peninsula we find deposits of alluvial tin ore, producing what is known in commerce as Straits tin A little to the east are the islands of Banca and Billiton, which for many years have been a source of wealth to the Dutch Government The sales of Banca tin in 1881 amounted to 4339 tons, and those of Billiton tin to 473[illegible] tons, whilst 11,475 tons of Straits tin were exported from Penang and Singapore [4] Stanniferous alluvia are also worked in Karimon, Singkep, and Sumatra, whilst the latter island possesses also valuable seams of coal

Borneo furnishes coal, antimony ore, and some cinnabar, and river gravels are washed for diamonds gold and platinum

There is no doubt that the mineral wealth of China is enormous In addition to important coal fields it possesses numerous metallic mines The province of Yunnan in the south of the empire seems to be specially favoured with regard to metalliferous wealth, for mines of gold, silver copper, lead, tin and iron are worked there, whilst jade and precious stones are found in the beds of rivers

Japan produces more than 3000 tons of copper yearly, or about as much as the British Isles The output of lead and tin is insignificant but the quantity of silver, exceeding 300 000 oz yearly, is worthy of notice Gold iron, and petroleum are other products of Japan

The gold of Siberia has been mentioned in speaking of Russia

Canada —The Dominion of Canada is rich in minerals Gold bearing quartz veins are worked in Nova Scotia, whilst in British Columbia alluvial deposits are the main source of the supply Silver occurs on Lake Superior the most important mine being that of Silver Islet which from 1869 to the spring of 1877 yielded 2½ million ounces of silver, and gave a profit of £200,000

Rocks resembling the copper bearing strata of the United States territory are mined in Michipoten island in Lake Superior Iron ores, in the form of magnetite red hæmatite limonite, and ilmenite, are worked in various parts of Canada

Petroleum is derived from oil wells in Western Ontario and the quantity refined in 187[illegible] was about 210 000 barrels each of 40 gallons It is in Ontario also that the veins of apatite exist from which a large amount of that useful mineral has been raised

United States —The mineral wealth of the United States is admirably summed up by Mr Richard P Rothwell in his address to the American Institute of Mining Engineers [5]

"*Production of Coal Metals, and Petroleum in* 1881 [6]

Anthracite	[illegible] 940 tons	(of 2240 ℔)
Bituminous coal	42 41[illegible]	([illegible] ℔)
Pig iron	4 144 [illegible]	(of [illegible]40 ℔)
Lead	10[illegible] 000	
Copper	31 000	
Quicksilver	[illegible] flasks	(of [illegible] lb avoir
Gold	[illegible]	(=[illegible] oz)
Silver	[illegible] 000	(= [illegible] oz)
Petroleum	2[illegible]64 000 barrels	(of [illegible] gallons)

"The statistics of other useful minerals and metals show an equally marvellous advance during the past thirty years The production of pig iron which in 1851 was [illegible]41 000 net tons in 1861 was [illegible] 000 tons and in 1871 was 1 [illegible] 000 tons. Ten years later in 1881 we produced no less than 4 141 000 tons an increase in thirty years of nearly 800 per cent

Lead which appears at 14 400 tons in 1852 varied but little from that figure until the construction of railroads into the argentiferous lead mining district of the west about 1870 Eureka Nevada Utah and more recently Colorado with its Leadville bonanzas rapidly raised the production from 1[illegible] 000 tons in 1871 to [illegible] 000 tons in 187[illegible] [illegible] 000 tons in 1877 and 10[illegible] tons in 1881

Our production of copper steadily increased from 1000 tons in 1852 to 31 000 tons in 1881 —the enormous output of that unrivalled mine Calumet and Hecla steadying the production and neutralizing the [illegible]

Quicksilver has shown wide fluctuations due more to trade combinations than to the condition of the mines In 1882 the output amounted to [illegible] flasks but it went as low as 10 000 flasks in 1860 and rose to 53 000 flasks five years later from this it declined to 1[illegible] 000 flasks in 1875 though in the following year it grew to 75 000 flasks Last year we produced 59 000 flasks

---

[1] A Cordella Mineralogisch geologische Reiseskizzen aus Griechenland ' *Berg und huttenmannische Zeitung* vol xlii 1883 p 21

[2] A J Macdonald The Value of the Cape as a Dependency of Great Britain," *The Times*, 3d May 1883

[3] *Statistical Abstract for the Several Colonial and other Possessions of the United Kingdom in each year from* 1860 *to* 1880 London 188[illegible] p [illegible]

[4] Hunt, *Min Stat* for 1881 p 9

[5] *Engineering and Mining Journal* vol xxxiv p 1[illegible]4

[6] The total production of coal in the United States in 1882 amounted to 86,862 614 tons of 2240 ℔ (*Colliery Guardian* for 188[illegible] p [illegible]) The quantities of metals produced in 1882 are estimated to be—pig iron 4 [illegible]23 323 gross tons of 2240 ℔ each lead 12[illegible] 000 gross tons, copper 40 00[illegible] gross tons (*The Iron, Steel and Allied Trades in* 1882 p 188 *Eng and Min Jour* vol xxxv p [illegible])

Gold is the only metal in which our production has been declining In 1852 it amounted to $60 000 000 but with some fluctuations it has now declined to less than $32 000 000 annually

The production of silver on the contrary has largely increased Commencing in 1859 with $100 000 it has now attained $45 000 000 In 1877 only were these figures exceeded and then only by about $1 000 000

"The production of petroleum that great American industry has grown with wonderful rapidity In 1859 it commenced with only [illegible]000 barrels and after an almost uniform increase it attained last year the enormous figures of 27 000 000 barrels Scientific investigation has recently raised a note of warning in this industry asserting the limited area of oil producing territory and its approaching exhaustion

Some valuable statistics concerning the production of the precious metals in the United States are contained in a report issued by the Census Bureau [1] The output for the year ended 31st May 1880 is summed up as follows —

	Gold		Silver		Total
	Ounces	Value	Ounces	Value	Value
Deep mines	1 03[illegible] [illegible]74	$21 [illegible]	31 [illegible]17 [illegible]97	$41 007 296	$62 881 448
Placers	580 767	12 00[illegible] 511	80 177	103 661	12 109 172
All mines	1 614 741	[illegible]	31 [illegible]	41 110 957	74 490 620

The State producing the greatest value is Colorado, viz, $19,249 172, or gold 130 607 oz and silver 12,800 119 oz, California comes next having produced $18,301,828 of bullion, and then Nevada with $17 318 909 of bullion

The greatest gold producer among the States and Territories is California with 829 676 oz of gold, half from deep mines and half from placers Next follows Nevada, with 236,468 oz of gold, of which only about 1 per cent came from placer mines then Dakota, 159 920 oz of gold, nearly entirely produced by deep mines, and in the fourth rank Colorado, 130,607 oz, with a placer production of less than [illegible]000 oz

The greatest silver producer is Colorado, with 12,800 119 oz, then Nevada 9 614 561 oz then Utah, 3 668 365 oz, Montana, 2 246,938 oz and fifthly Arizona 1,798 920 oz

It is useless within the limits of this article to attempt to convey an adequate idea of the enormous mineral resources of the United States We can merely very briefly allude to some of the principal deposits, which are of commercial value on account of their magnitude of scientific interest owing to their mode of occurrence, and of technical importance as having led to the introduction of considerable improvements in the arts of mining, milling and dressing

Among these may be mentioned the coal and anthracite mines and oil wells of Pennsylvania the gold and quicksilver mines of California, the silver mines of Nevada the lead and silver mines of Colorado and the copper mines of Lake Superior The articles COAL (vol vi p 60) and GOLD (vol x p 743) may be referred to for information concerning the occurrence of these minerals and the method of extracting gold by hydraulic mining and improved stamping machinery

Quicksilver in the form of native mercury and cinnabar occurs in considerable abundance in California and much of it is found in connexion with serpentine either in the serpentine itself or in sandstone near its junction with serpentine The most important mines are those of New Almaden in the southern part of the State near San Jose The deposit at Sulphur Bank in Lake County is of much geological interest It consists of native sulphur, gypsum, and cinnabar in a decomposed andesitic lava close to an extinct geyser from which boiling water still issues The top of the bank was worked open cast for sulphur, and then for sulphur and cinnabar and now underground mining is carried on in stratified sandstone and shale impregnated with cinnabar and underlying the lava

Some of the most marvellous silver mines in the world are those upon the Comstock lode in Nevada A horizontal section of part of this great vein is shown on Plate IV, copied from the excellent and well known report of Mr J D Hague [2] The strike is nearly north and south and the dip about 43° to the east "The vein matter of the Comstock consists of crushed and decomposed country rock clay and quartz Up to January 1, 1880, the Comstock had yielded in twenty years about $325 000 000 worth of bullion The total length of shafts and galleries is about 250 miles The number of men employed in the mines in January 1880 was 2800 earning average wages of $4 a day At the same date 340 men were at work in the amalgamating mills [3] The heat of the Comstock lode is remarkable On the 2700 feet level of the Yellow Jacket mine Mr Becker found the temperature of the water to be 153°, that of the air 126° whilst the water in the Yellow Jacket shaft at a depth of 3065 feet has a temperature of 170° Fahr [4]

During the last few years the Comstock lode has been falling off in productiveness In 1876 the total yield of the Comstock lode was $38,572,984 (gold, $18,002,906, silver, $20,570,078) During the census year ending May 31, 1880, the product of the whole Comstock district, including outlying veins, was $6,922,330 (gold, $3,109,156, silver, $3,813,174), showing a decline of $31,650,654, or 82 06 per cent, since 1876 [5]

Though the extraction of silver from its ores may be regarded as the business of the metallurgist rather than of the miner, we must not forget to mention that it is to the necessities of the treatment of the Nevada ores that we owe the system of pan amalgamation first developed in that State and practised since in Colorado

Another district in Nevada which *cannot be passed over in* silence is that which contains the Eureka and Richmond mines which are celebrated, not only for the silver they have produced, but also for the important trial in which the issue hinged upon the definition of the term vein or lode (p 441) The bullion produced in the Eureka district from ore raised and treated during the census year ended May 31, 1880, was—gold, 62,893 oz, and silver, 2,037,666 oz, worth altogether $3,934,621 [6]

The history of Leadville in Colorado seems like a romance when we read of the rapid development of the mines the creation of a large and important town, the erection of smelting works and the building of railways, under very adverse conditions, in the heart of the Rocky Mountains, all within the space of four or five years It affords additional proof that the miner is the true pioneer of civilization The main facts concerning the Leadville deposits are admirably summed up by Mr S F Emmons, from whose report [7] we borrow, not only the following facts, but also the geological section across the district (Plate IV)

The principal deposits of the region are found at or near the junction of the porphyry with the Blue limestone, which is the lowest member of the Carboniferous formation This bed is about 150 or 200 feet thick, and consists of dark blue dolomitic limestone At the top there are concretions of black chert The porphyry occurs in intrusive sheets which generally follow the bedding, and almost invariably a white porphyry is found overlying the Blue limestone This porphyry is of Secondary age it is a white homogeneous looking rock, composed of quartz and felspar of even granular texture, in which the porphyritic ingredients, which are accidental rather than essential, are small rectangular crystals of white felspar, occasional double pyramids of quartz, and fresh hexagonal plates of biotite or black mica Along the plane of contact with the porphyry the limestone has been transformed by a process of gradual replacement, into a vein consisting of argentiferous galena, cerussite, and cerargyrite mixed with the hydrous oxides of iron and manganese chert, granular cavernous quartz clay, heavy spar, and 'Chinese talc, a silicate and sulphate of alumina The vein seems to have been formed by aqueous solutions, which took up their contents from the neighbouring eruptive rocks and brought about the alteration of the limestone as they percolated downwards through it In Carbonate Hill, a gradual passage may be observed from dolomite into earthy oxides of iron and manganese The masses of workable ore are extremely irregular in shape size and distribution They are often 30 to 40 feet thick vertically, and occasionally 80 feet, but only over a small area The rich ore bodies are commonest in the upper part of the ore bearing stratum At Fryer Hill the Blue limestone is almost entirely replaced by vein material

In the census year ended May 31, 1880, Lake County, Colorado, which includes the Leadville district, produced 28,226 gross tons of lead, with 3830 oz of gold and 8,853,946 oz of silver, of a total value of $13 032,464 [8]

The most important copper mines of the United States are those on Lake Superior, where the native metal occurs 'in veins in large masses, or scattered more or less uniformly in certain beds which are either amygdaloid or conglomerates [9] The principal copper producing districts are in Michigan where the Portage Lake district in Houghton county, contains the famous Calumet and Hecla mine, which alone produced 15,837 tons of copper in 1880 or about half the entire output of the United States The deposit from whence this vast amount of copper was obtained is a bed of conglomerate, generally called a vein, dipping about 38° north west It has been worked for a depth of 2[illegible]50 feet on the incline In 187[illegible] the stuff stamped yielded 4½ per cent of copper

In conclusion, we will point out that the value of the mining *industry in the United States exceeds that of any other country in* the world, Mr Porter estimating it for 1879 1880 at 360 million dollars, and that of Great Britain at 325 millions [10] Germany holds

---

[1] Clarence King special agent of the Census *Statistics of the Production of the Precious Metals in the United States* Washington 1881 p [illegible]

[2] *United States Geological Exploration of the Fortieth Parallel* vol iii Mining Industry Atlas plate 11

[3] Clarence King *First Annual Report of the U S Geological Survey* p 39

[4] *Op cit* pp 44 45

[5] Clarence King *Statistics of the Production of the Precious Metals in the United States* Washington 1881, p 19

[6] *Op cit* p 21

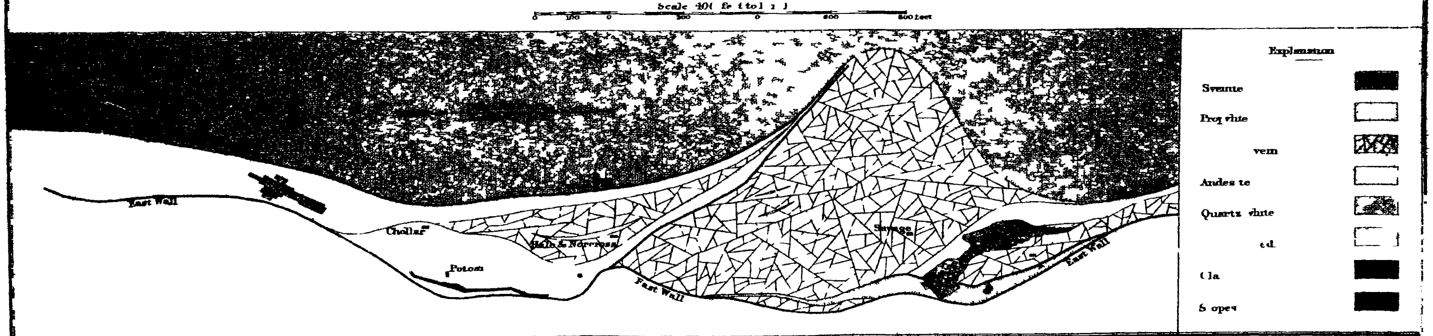
[7] *Abstract of a Report upon the Geology and Mining Industry of Leadville, Colorado* Washington 1882

[8] Clarence King *op cit* p 47

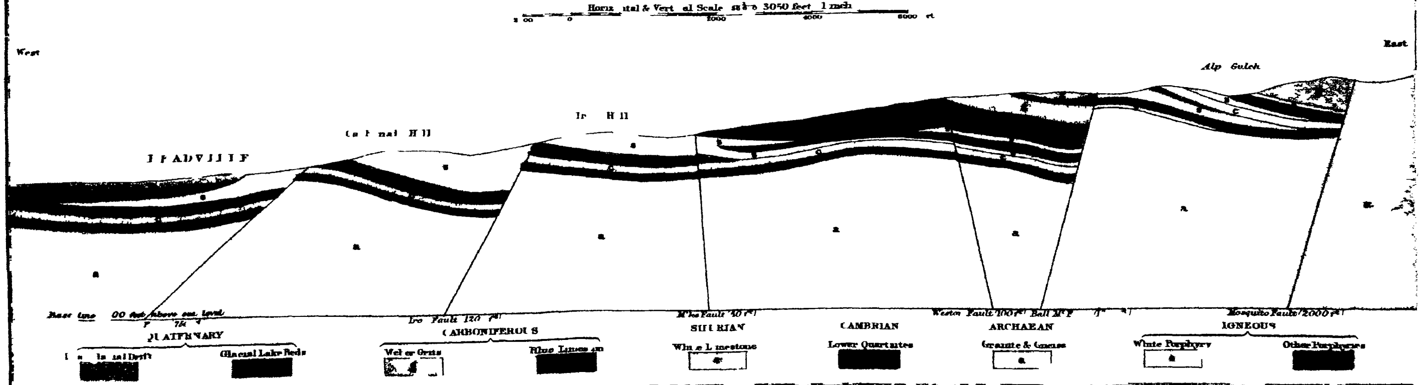
[9] Charles E Wright commissioner *Annual Report of the Commissioner of Mineral Statistics for the State of Michigan for* 1880 Lansing Michigan 1881

[10] Robert P Porter *The West from the Census of* 1880, Chicago and London 1882 p 19

HORIZONTAL SECTION OF PART OF THE COMSTOCK LODE 331 FEET BELOW THE OUTCROP AT GOULD & CURRY MINE



EAST AND WEST SECTION ACROSS PART OF THE LEADVILLE MINING DISTRICT



the third rank followed by France and Russia The United States produce 33 per cent [1] of the gold yield of the whole world 50 per cent of the silver 22 per cent of the pig iron [2] 29 per cent of the steel and about 25 per cent of the lead

Mexico has been renowned for its gold and silver mines ever since the Spaniards first took possession of it and its production is still very considerable Indeed after the United States it still produces far more silver than any other country in the world The average annual output of silver during the twenty five years 1851 to 1875 is estimated by Dr Adolf Soetbeer at 501 520 kilogrammes or 16 124 235 oz [3] whilst the average annual output of gold during the same period was 1785 kilogrammes or 57 389 oz Tin ore occurs in considerable quantities in Mexico and is likely to be worked on a large scale as soon as the tin district is opened up by a railway

Central America possesses numerous gold mines

South America —Venezuela produces gold copper and a little lead The copper is found at Aroa near the north coast and the gold in the province of Guiana which is now producing upwards of 100 000 oz annually It is highly probable that the existence of this gold was known to the Indians who reported it to Sir Walter Raleigh and so led him to undertake his unfortunate expedition in search of El Dorado French Guiana contains workable deposits of gold and yielded 72 168 oz in 1880

The chain of the Andes forms a long belt of mineral producing country Beginning with the United States of Colombia we have a country rich in gold—the State of Antioquia being especially favoured in this respect The annual yield of all the states is about 200 000 oz Colombia has mines of rock salt yielding 19 000 tons a year and the emerald mine at Muzo has long been famous Peru is renowned for its silver mines the best known are those of Cerro de Pasco situated at an elevation of 14 000 feet above the sea level Passing into Bolivia we must notice the silver mines of Potosi the wealth of which is proverbial Chili is best known as the principal copper producing country of South America but its silver mines are not unimportant and beds of nitrate of soda are largely wrought

The most remarkable gold mines of Brazil lie in the province of Minas Geraes whilst diamonds are obtained in that of Matto Grosso In the Argentine Republic gold silver and copper mines are worked especially in the provinces on the eastern flanks of the Andes

The total annual output of the precious metal in South America is estimated to be upwards of 300 000 oz of gold and 2 000 000 oz of silver In 1877 Chili exported 35 128 metric tons of metallic copper in addition to ore and regulus

Australia —Australia is remarkably rich in minerals especially gold (see GOLD vol x p 744 tin and copper and its coal deposits are likely to be largely utilized in the future

Queensland though a young colony has already made itself famous for gold and tin and it also possesses vast resources of coal and copper in addition to the ores of other metals The quantity of gold sent by escort from the different gold fields was 904 388 oz in 1880 in addition to what was carried by private hands Tin ore was first worked in 1872 near the border of the colony with New South Wales and large quantities of stream tin have been obtained from very shallow alluvial diggings near Stanthorpe Like gold the tin ore is not confined to one district it occurs and is worked at the North Palmer diggings a little to the south is Great Western rich in tin ore and so is Herberton to the north east on the other side of the Dividing range

In 1881 New South Wales [4] produced minerals and metals worth £2 373 191 viz 149 627 oz of gold 1 775 224 tons of coal 8200 tons of tin 5493 tons of copper 6560 tons of iron besides silver oil shale and antimony In addition to the facts concerning the occurrence of gold already mentioned (*loc cit*) it is interesting to note that auriferous conglomerates containing the precious metal in payable quantities have been discovered and worked in this colony in rocks of the age of the Coal Measures [5] The most important tin district is that of Vegetable Creek in New England which from 1872 to 1880 produced 20 988 tons of tin ore The accompanying map (fig 105 [6]) shows the recent alluvium which has hitherto been the main source of the supply and the deep leads which as far as explored at present promise still greater riches The section (fig 106 [6]) shows that these deep leads like those of the gold fields (GOLD vol x p 743) are old alluvia preserved under a capping of basaltic lava There are also numerous tin lodes which are beginning to be worked

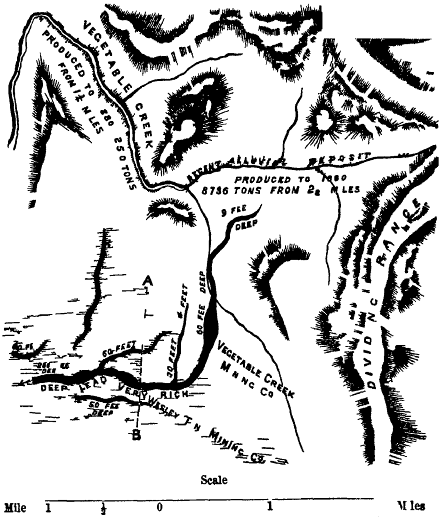


FIG 105 Sketch Map of Part of Vegetable Creek New South Wales showing recent and ancient tin deposits The stippled part represents tin bearing alluvium The shaded part AB denotes basalt which has covered the lower portions of the ancient tin bearing alluvia (deep leads) as explained in fig 106 The rest is granite

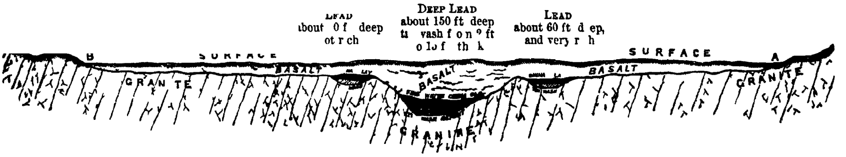


FIG 106 —Enlarged Section (on AB of fig 105) across Deep Leads in Vegetable Creek New South Wales

Victoria heads the list of gold producing British colonies having yielded in 1882 [7] as much as 864 610 oz of which 35[illegible] 078 oz were derived from alluvial deposits and 1[illegible] 3[illegible] oz from quartz mines 1077 tons of tin ore were raised and 3[illegible] tons of antimony ore

South Australia is the great copper producing province though the yield is not so great as it was ten years ago All the principal mines now at work are on Yorke's Peninsula In 1881 [8] South Australia produced 38[illegible]4 tons of copper worth £[illegible]63 3[illegible]0 and 21 638 tons of copper ore worth £154 926

In 1881 Western Australia exported 1400 tons of lead ore valued at £11 204

Tasmania like some parts of Australia is rich in tin ore which is now obtained principally from an alluvial deposit at Mount Bischoff The ore is now almost entirely smelted in the colony and in 1880 the exports were 3951 tons of metal and 3 tons of ore worth altogether £341 736

New Zealand furnishes a considerable amount of gold from quartz reefs and alluvial diggings The annual exports during the ten years 1862 to 1872 were often [illegible]00 000 and even [illegible]00 000 oz Of late years the yield has gradually diminished and in 1880 only 303 215 oz valued at £1 220 263 were exported Silver is exported to the extent of 20,000 to 30 000 oz annually it is mainly derived from the gold obtained in the Thames district which contains about 30 per cent of the less valuable metal Coal is worked in several places but the total output is at present comparatively small

---

[1] Clarence King *op cit* p 93

[2] James M Swank *Statistics of the Iron and Steel Productions of the United States* Washington 1881 p 17

[3] Dr Adolf Soetbeer *Edelmetall Produktion* Gotha 18[illegible]9 p 6

[4] *Annual Report of the Department of Mines New South Wales for the year* 1881 Melbourne 1882 p 8

[5] *Annual Report of the Department of Mines New South Wales for the year* 1876 Sydney 1877 p 173

[6] Furnished by Mr W H Wesley

[7] *Mineral Statistics of Victoria for the year* 1882 Melbourne 1883 p 7

e of South Australia for the year 1881

New Caledonia —The discovery of nickel ore in this island by M Garnier in 1867 was one of great mineralogical interest, and it has since borne fruits of considerable commercial importance The New Caledonian ores are hydrous silicates of nickel and magnesium, which occur in veins in serpentine and contain from 7 to 18 per cent of nickel The mineral is found on the Mont d Or not far from Noumea Most of the ore is sent to France to be treated

To the list of works on mining mentioned in the article Coal (vol vi. p 81) the following may be added —Callon *Cours d exploitation des Mines* Paris, 1874 and English translation by C Le Neve Foster and W Galloway, Serlo, *Leitfaden zur Bergbaukunde* Berlin 1878 Zoppetti *Arte mineraria* Milan, 1882 A von Groddeck *Die Lehre von den Lagerstatten der Erze* Leipsic 1879, P von Rittinger *Lehrbuch der Aufbereitungskunde* Berlin 1867 *Jahrbuch fur das Berg und Huttenwesen im Konigreiche Sachsen* Freiberg annually *Annual Reports of H M Inspectors of Mines* *Preliminary Report of Her Majesty s Commissioners Appointed to Inquire into Accidents in Mines* London 1881, *Annales des Mines* Paris 6 parts published yearly *The Engineering and Mining Journal* New York published weekly *Transactions of the American Institute of Mining Engineers* Philadelphia *Die berg und huttenmannische Zeitung* Leipsic, weekly *Oesterreichische Zeitschrift fur Berg und Huttenwesen* Vienna, weekly (C L N F)

MINISTRY Ever since the introduction of monarchical institutions into England the sovereign has always been surrounded by a select body of confidential advisers to assist the crown in the government of the country At no period could a king of England act, according to law, without advice in the public concerns of the kingdom, the institution of the crown of England and the institution of the privy council are coeval At the era of the Norman Conquest the kings council, or as it is now called the privy council, was composed of certain select members of the aristocracy and great officers of state, specially summoned by the crown, with whom the sovereign usually advised in matters of state and government In the earlier stages of English constitutional history the kings councillors, as confidential servants of the monarch, were present at every meeting of parliament in order to advise upon matters judicial in the House of Lords, but in the reign of Richard II the privy council dissolved its judicial connexion with the peers and assumed an independent jurisdiction of its own It was in the reign of Henry VI that the kings council first assumed the name of privy council, and it was also during the minority of this sovereign that a select council was gradually emerging from out of the larger body of the privy council, which ultimately resulted in the institution of the modern cabinet Since the Revolution of 1688, and the development of the system of parliamentary government, the privy council has dwindled into comparative insignificance when contrasted with its original authoritative position The power once swayed by the privy council is now exercised by that unrecognized select committee of the council which we call the cabinet The practice of consulting a few confidential advisers instead of the whole privy council had been resorted to by English monarchs from a very early period, but the first mention of the term cabinet council in contradistinction to privy council occurs in the reign of Charles I, when the burden of state affairs was intrusted to the committee of state which Clarendon says was enviously called the "cabinet council" At first government by cabinet was as unpopular as it was irregular Until the formation of the first parliamentary ministry by William III the ministers of the king occupied no recognized position in the House of Commons, it was indeed a moot point whether they were entitled to sit at all in the lower chamber, and they were seldom of one mind in the administration of matters of importance Before the Revolution of 1688 there were ministers, but no ministry in the modern sense of the word, colleague schemed against colleague in the council chamber, and it was no uncommon thing to see ministers opposing one another in parliament upon measures that ought to have been supported by a united cabinet As the exchange from government by prerogative to government by parliament, consequent upon the Revolution of 1688, developed, and the House of Commons became more and more the centre and force of the state, the advantage of having ministers in the legislature to explain and defend the measures and policy of the executive Government began gradually to be appreciated The public authority of the crown being only exercised in acts of administration, or, in other words, through the medium of ministers, it became absolutely necessary that the advisers of the sovereign, who were responsible for every public act of the crown as well as for the general policy they had been called upon to administer, should have seats in both Houses of Parliament The presence of ministers in the legislature was the natural consequence of the substitution of government by parliament for the order of things that had existed before 1688 Still nearly a century had to elapse before political unanimity in the cabinet was recognized as a political maxim From the first parliamentary ministry of William III until the rise of the second Pitt divisions in the cabinet were constantly occurring, and a prime minister had more to fear from the intrigues of his own colleagues than from the tactics of the opposition In 1812 an attempt was made to form a ministry consisting of men of opposite political principles, who were invited to accept office, not avowedly as a coalition Government, but with an offer to the Whig leaders that their friends should be allowed a majority of one in the cabinet This offer was declined on the plea that to construct a cabinet on "a system of counteraction was inconsistent with the prosecution of any uniform and beneficial course of policy" From that date it has been an established principle that all cabinets are to be formed on some basis of political union agreed upon by the members composing the same when they accept office together It is now also distinctly understood that the members of a cabinet are jointly and severally responsible for each others acts, and that any attempt to separate between a particular minister and his colleagues in such matters is unfair and unconstitutional

The leading members of an administration constitute the Cabinet (*q v*) The members of an administration who are sworn of the council, but who are not cabinet ministers, are the lord lieutenant of Ireland, the vice president of the council for education, the judge advocate general, and the chief officers of the royal household The subordinate members of an administration who are never in the cabinet, and who are seldom raised to the distinction of privy councillors, are the junior lords of the treasury, the joint secretaries to the treasury, the paymaster general, the junior lords of the admiralty, the parliamentary under-secretaries of state, and the law officers of the crown

During the present century the power of ministers has been greatly extended, and their duties more distinctly marked out Owing to the development of the system of parliamentary government, much of the authority which formerly belonged to English sovereigns has been delegated to the hands of responsible ministers As now interpreted, the leading principles of the British constitution are the personal irresponsibility of the sovereign, the responsibility of ministers, and the inquisitorial power of parliament At the head of affairs is the prime minister, and the difference between theory and practice is curiously exemplified by the post he fills The office is full of anomalies Like the cabinet council the prime minister is unknown to the law and the constitution, for legally and according to the fictions of the constitution no one privy councillor has as such any superiority over another, yet practically the premier is the pivot on which the whole administration turns. He is the medium of intercourse between the cabinet and the sovereign; he has to be cognizant of all matters of real importance that take place in the different departments so as to exercise a controlling influence in the cabinet; he is virtually responsible for the disposal of the entire patronage of the crown; he selects his colleagues, and by his resignation of office dissolves the ministry. Yet, though entrusted with this power, and wielding an almost absolute authority, he is in theory but the equal of the colleagues he appoints and whose opposition he can silence by the threat of dissolution. The prime minister is nominated by the sovereign. "I offered," said Sir Robert Peel on his resignation of office, "no opinion as to the choice of a successor. That is almost the only act which is the personal act of the sovereign; it is for the sovereign to determine in whom her confidence shall be placed." Yet this selection by the crown is practically limited. No prime minister could carry on the government of the country for any length of time who did not possess the confidence of the House of Commons; and royal favour, if it were ever invidiously exercised, would ultimately have to yield to a regard for the public interests. As a general rule the prime minister holds the office of first lord of the treasury, either alone or in connexion with that of chancellor of the exchequer. Before 1806 the premiership was occasionally held in connexion with different other offices,—a secretaryship of state, the privy seal, and the like,—but it is now almost invariably associated with the post of first lord of the treasury. With the exception of the premier, whose duties are more general than departmental, the work of the other members of the administration is exemplified by the title of the offices to which they are called. The lord chancellor, in addition to the jurisdiction which he exercises in his judicial capacity, is prolocutor of the House of Lords by prescription, the keeper of the sovereign's conscience, the general guardian of all infants, idiots, and lunatics, and to him belongs the appointment of all the justices of the peace throughout the kingdom. In former times the lord chancellor was frequently prime minister; the earl of Clarendon in the reign of Charles II., however, was the last who occupied that position. The lord president of the council, who is always a member of the Upper House, presides over the department of the privy council, exercises a general superintendence over the education department, and has to frame minutes of council upon subjects which do not belong to any other department of state. Subordinate to his department are separate establishments in relation to public health, the cattle plague, and quarantine. The post of lord privy seal is one of great trust, though its duties are not very onerous, since they simply consist in applying the privy seal once or twice a week to a number of patents. Ever since the days of Henry VIII. the privy seal has been the warrant of the legality of grants from the crown and the authority of the lord chancellor for affixing the great seal. The lord privy seal is always a member of the cabinet. As his official duties are light he is at liberty to afford assistance to the administration in other ways, and he has often to attend to matters which require the investigation of a member of the Government.

The secretaries of state are among the most important members of the ministry, and within the present century their number has been increased and their duties more specially consolidated. The ancient English monarchs were always attended by a learned ecclesiastic, known at first as their clerk, and afterwards as secretary, who conducted the royal correspondence; but it was not until the end of the reign of Queen Elizabeth that these functionaries were called secretaries of state. Upon the direction of public affairs passing from the privy council to the cabinet after 1688, the secretaries of state began to assume those high duties which now render their office one of the most influential of an administration. Until the reign of Henry VIII. there was generally only one secretary of state, but at the end of his reign a second principal secretary was appointed. Owing to the increase of business consequent upon the union of Scotland, a third secretary, in 1708, was created, but a vacancy occurring in this office in 1746 the third secretaryship was dispensed with until 1768, when it was again instituted to take charge of the increasing colonial business. However, in 1782 the office was again abolished, and the charge of the colonies transferred to the home secretary; but owing to the war with France in 1794 a third secretary was once more appointed to superintend the business of the war department, and seven years later the colonial business was attached to his department. In 1854 a fourth secretary of state for the exclusive charge of the war department and in 1858 a fifth secretaryship for India were created. There are therefore now five principal secretaries of state, four of whom, with their political under secretaries, occupy seats in the House of Commons. One of these secretaries of state is always a member of the House of Lords. The secretaries of state are the only authorized channels through which the royal pleasure is signified to any part of the body politic, and the counter signature of one of them is necessary to give validity to the sign manual; thus while the personal immunity of the sovereign is secured a responsible adviser for every act is provided who has to answer for whatever course the crown has pursued. The secretaries of state constitute but one office, and are coordinate in rank and equal in authority. Each is competent in general to execute any part of the duties of the secretary of state, the division of duties being a mere matter of arrangement. These duties are of the deepest importance to the welfare of the nation. The home secretary controls all matters relating to the internal affairs of the country; he is responsible for the preservation of the public peace and for the security of life and property throughout the kingdom; he exercises extensive powers over the civil and military authorities of the country, and has a direct controlling power over the administration of justice and police in the municipal boroughs, over the police in and around London and over the county constabulary; and he is especially responsible for the exercise of the royal prerogative in the reprieve or pardon of convicted offenders or the commutation of their sentences. The foreign secretary, as his name implies, is the official organ of the crown in all communications between Great Britain and foreign powers; he negotiates all treaties or alliances with foreign states, protects British subjects residing abroad, and demands satisfaction for any injuries they may sustain at the hands of foreigners. The secretary of state for the colonies has to superintend the government of the various colonial possessions of the British crown; he appoints the governors over the different dependencies of the crown, and sanctions or disallows the enactments of the colonial legislatures. This latter power has of late years been much curtailed owing to the establishment of responsible government in most of the colonies; still it is the duty of the secretary of the colonies to correspond with the colonial governors and to offer such suggestions as may be expedient to assist the deliberations of the colonial councils and to promote the welfare of colonial subjects. Until the year 1854 the direction of military affairs was practically divided between the commander in chief at the horse guards, the board of ordnance, the secretary at war, and the secretary of state for war and the colonies. Upon the declaration of hostilities, however, against Russia in 1854 the duties of war minister were separated from those of colonial secretary, and a secretary of state for war appointed, in whose hands the supreme and responsible authority over the whole military business of the country formerly transacted by the various departments was placed. The actions of the commander in chief are subject to the approval of the secretary of state for war. The duties of the commander in chief embrace the discipline and patronage of the army and the direct superintendence of the *personnel* of the army; with the exception of those duties everything connected with the management of the army in peace or war (its *matériel* and civil administration, &c.) remains in the hands of the war minister. The subordinate position of the commander in chief is the result of the British system of parliamentary government. The secretary of state for war is the minister of the crown and not of parliament, although he is responsible to parliament for the advice he may give to the sovereign; yet it is in the execution of the royal authority and prerogative that he is superior to the officer commanding in chief. The principle of the constitutional army is that command, preferment, and honour come to it from the crown; but the general principle is equally undisputed that for all pecuniary remuneration it is made to depend on parliament. By the constitution the crown exercises its authority only through responsible advisers, and hence it follows that the secretary of state for war is supreme over any authority in the army, including the officer commanding in chief. From 1784 to 1858 the territories belonging to the British crown in the East Indies were governed by a department of state called the board of control in conjunction with the court of directors of the East India Company In 1858 this double government was abolished, and the entire administration of the British empire in India was assumed by the crown, and all the powers formerly exercised by the East India Company and the board of control were [illegible] The secretary for [illegible] osal, and the governor general of India is subject to his control To assist him in his labours, and to act as a check upon the exercise of his otherwise arbitrary administrative powers, this secretary has the aid of a council of state for India, consisting of fifteen persons of which, however, he is the president The members of the council for India cannot sit in the House of Commons

The duties of the other members of the ministry can be briefly dismissed The chancellor of the exchequer at present exercises all the powers which formerly devolved upon the treasury board, he has the entire control of all matters relating to the receipt and expenditure of public money, he frames the annual estimates of the sums required to defray the expenditure of government in every branch of the public service and it is his duty to lay before the country the annual statement of the estimated expenses of government and of the ways and means by which it is proposed to defray those charges including the imposition or remission of taxes The first lord of the admiralty (since the abolition of the office of lord high admiral) with the aid of the junior lords who are called the lords of the admiralty conducts the administration of the entire naval force of the empire both at home and abroad and is responsible to parliament for all his political proceedings as the admiralty is but an executive board, it is however, subject on certain matters —the number of men required for the naval service the distribution of the fleet the strength of foreign squadrons &c —to the control of the cabinet The president of the board of trade takes cognizance of all matters relating to trade and commerce and has to protect the mercantile interests of the United Kingdom, until 1864 it was not necessary for the president to have a seat in the cabinet but since that date he has always been a cabinet minister in order to insure for his advice on commercial matters a due consideration in 1867 the office of vice president of the board was abolished The chancellor of the duchy of Lancaster exercises jurisdiction over all matters of equity relating to lands held of the crown in right of the duchy of Lancaster the office is however practically a sinecure and is usually filled by a leading statesman whose time is at the service of the Government for the consideration of such important questions as do not come within the province of other departments In 1832 the public works and buildings of Great Britain were for the first time placed under the control of a responsible minister of the crown, and were assigned to the charge of the commissioners of woods and forests but in 1851 the department of public works was separated from the woods and forests and erected into a board under the name of the office of her majesty's works and public buildings The first commissioner of works is the head of the board and in his hands is placed the custody of the royal palaces and parks and of all public buildings not specially assigned to the care of other departments Since the establishment of his office the first commissioner has frequently had a seat in the cabinet The duties of the postmaster general of the president of the local government board and of the minor members of the administration are so obvious from the titles of the offices they hold as not to call for any special mention

The prime minister is responsible for the distribution of the chief offices of government between the two Houses of Parliament Owing to the development of the House of Commons within the present century it is now considered advisable that a larger proportion of cabinet ministers should have seats in that chamber than was formerly the case In the first cabinet of George III only one of its members was in the House of Commons and thirteen in the House of Lords In 1783 Mr Pitt was the sole cabinet minister in the Commons In 1801 four cabinet ministers were in the Commons and five in the Lords In 1804 Mr Pitt and Lord Castlereagh were, out of a cabinet of twelve, the only ministers in the Commons In the Grenville ministry (' All the Talents '), of a cabinet of eleven, seven were in the Lords and four in the Commons In 1809, of Mr Perceval's cabinet, six were peers and four commoners In 1812, of Lord Liverpool's cabinet ten were peers and only two commoners In 1818, out of a cabinet of fourteen six were commoners, and in 1822, out of a cabinet of fifteen nine were peers Since the Reform Act of 1832, however, the leading members of Government have been more equally apportioned between the two Houses

See May *Constitutional History of England* Cox *Institutions of the English Government*, Alpheus Todd, *On Parliamentary Government*, Cooke *History of Party*

(A C E)

MINK The genus *Putorius*, belonging to the family *Mustelidæ* or Weasel like animals (see MAMMALIA, vol xv p 440), contains a few species called Minks, distinguished from the rest by slight structural modifications and especially by semiaquatic habits They form the subgenus *Lutreola* of Wagner, the genus *Vison* of Gray. As in other members of the genus, the dental formula is $i\,\frac{3}{3}$, $c\,\frac{1}{1}$, $p\,\frac{3}{3}$, $m\,\frac{1}{2}$, total 34 They are distinguished from the Polecats, Stoats, and Weasels, which constitute the remainder of the group, by the facial part of the skull being narrower and more approaching in form that of the Martens, by the premolar teeth (especially the first of the upper jaw) being larger, by the toes being partially webbed, and by the absence of hair in the intervals between the naked pads of the soles of the feet The two best known species, so much alike in size, form, colour, and habits that although they are widely separated geographically some zoologists question their specific distinction, are *P lutreola*, the *Norz* or *Sumpf otter* (Marsh Otter) of eastern Europe, and *P vison*, the Mink of North America The former inhabits Finland, Poland, and the greater part of Russia, though not found east of the Ural mountains Formerly it extended westward into central Germany, but it is now very rare, if not extinct, in that country The latter is found in places which suit its habits throughout the whole of North America Another form, *P sibiricus*, from eastern Asia, of which much less is known, appears to connect the true Minks with the Polecats

The name may have originated in the Swedish *maenk* applied to the European animal Captain John Smith, in his *History of Virginia* (1626), at p 27, speaks of ' Martins Powlecats, Weesels, and Minkes, ' showing that the animal must at that time have been distinguished by a vernacular appellation from its congeners By later authors, as Lawson (1709) and Pennant (1784), it is often written "Minx For the following description chiefly taken from the American form (though almost equally applicable to that of Europe) we are mainly indebted to Elliott Coues's *Fur bearing Animals of North America*, 1877

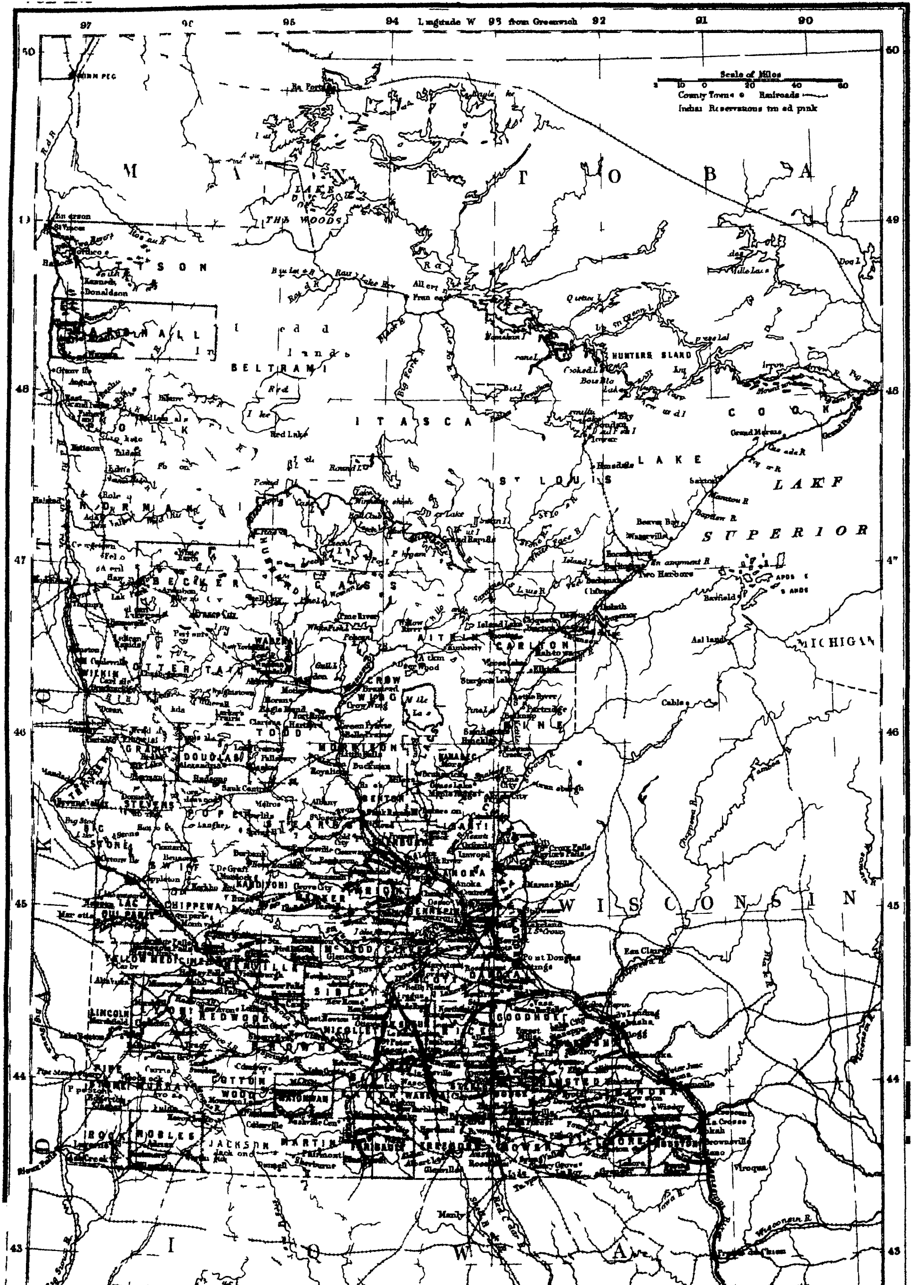
In size it much resembles the English Polecat, —the length of the head and body being usually from 15 to 18 inches that of the tail to the end of the hair about 9 inches The female is considerably smaller than the male The tail is bushy, but tapering at the end The ears are small, low, rounded, and scarcely project beyond the adjacent fur The pelage consists of a dense, soft matted under fur, mixed with long, stiff, lustrous hairs on all parts of the body and tail The gloss is greatest on the upper parts on the tail the bristly hairs predominate Northern specimens have the finest and most glistening pelage, in those from southern regions there is less difference between the under and over fur, and the whole pelage is coarser and harsher In colour, different specimens present a considerable range of variation, but the animal is ordinarily of a rich dark brown, scarcely or not paler below than on the general upper parts, but the back is usually the darkest, and the tail is nearly black The under jaw, from the chin about as far back as the angle of the mouth, is generally white In the European Mink the upper lip is also white, but, as this occasionally occurs in American specimens, it fails as an absolutely distinguishing character Besides the white on the chin, there are often other irregular white patches on the under parts of the body In very rare instances the tail is tipped with white The fur, like that of most of the animals of the group to which it belongs, is an important article of commerce

The principal characteristic of the Mink in comparison with its congeners is its amphibious mode of life It is to the water what the other Weasels are to the land, or Martens to the trees, being as essentially aquatic in its habits as the Otter Beaver or Musk rat, and spending perhaps more of its time in the water than it does on land It swims with most of the body submerged, and dives with perfect ease, remaining long without coming to the surface to breathe It makes its nest in burrows in the banks of streams, breeding once a year about the month of April and producing five or six young at a birth Its food consists of frogs, fish, freshwater molluscs and crustaceans, as well as mice, rats, musk rats, rabbits, and small birds In common with the other animals of the genus, it has a very peculiar and disagreeable effluvium, which, according to Coues, is more powerful, penetrating, and lasting than that of any animal of the country except the Skunk It also possesses the courage, ferocity, and tenacity of life of its allies When taken young, however, it can be readily tamed, and lately Minks have been extensively bred in captivity in America both for the sake of their fur and for the purpose of using them in like manner as Ferrets in England, to clear buildings of rats

(W H F)

MINNEAPOLIS, the county seat of Hennepin county, Minnesota, United States, and in 1880 the first city of the State as regards population, lies on both banks of the

MINNESOTA



ENCYCLOPÆDIA BRITANNICA NINTH EDITION

Mississippi, at the falls of St Anthony, 14 miles by river above St Paul The east side was first settled, under the name of St Anthony, which was incorporated as a city in 1860 The west side settlement, named Minneapolis, was incorporated as a city in 1867, and soon surpassed St Anthony in population In 1872 the two cities were united under the name of Minneapolis The chief industries are the manufacture of flour and of lumber, for which the falls supply abundant water power The Mississippi here flows over a limestone bed resting upon a friable white sandstone, hence erosion is rapid, and the river banks show that the falls have receded from a position at the mouth of the Minnesota river In 1851 90 feet of the limestone gave way at once, and, as the rock bed extends but 1200 feet above the present site of the falls, the destruction of the water power was threatened This has been averted by the construction of an apron, or inclined plane, of timber, with heavy cribwork at the bottom, and the building of a concrete wall in the bed of sandstone behind the falls and underneath the channel of the river For this work the United States Government appropriated $550,000 and the citizens of Minneapolis contributed $334,500 The city has twenty seven flour mills, which can produce 29,272 barrels a day The total product for the year ended September 1, 1882, was 2,301,667 barrels The shipments of lumber for 1880 were 164,620,000 feet The population in 1870 was 18,079 and in 1880, 46,887

MINNESANGER See GERMANY, vol x p 525

Plate V. MINNESOTA, one of the north western States of the American Union, extending from 43° 30 N lat to the British Possessions (about 49° N lat), and from Wisconsin and Lake Superior on the east to Dakota on the west, between the meridians of 89° 39 and 97° 5 W long Its area, including half of the lakes, straits, and rivers along its boundaries, except Rainy Lake and Lake of the Woods, amounts to 83,365 square miles

The surface of Minnesota is diversified by few elevations of any great height In general it is an undulating plain, breaking in some sections into rolling prairie, and traversed by belts of timber It has an average elevation above sea level of about 1000 feet The watershed of the north (which determines the course of the three great continental river systems) and that of the west are not ridges or hills, but elevations whose inclination is almost insensible The southern and central portions of the State are chiefly rolling prairie the upper part of which is crossed from N W to S E by the forest belt known as the Big Woods,—a stretch of deciduous forest trees with an area of about 5000 square miles North of the 47th parallel the great Minnesota pine belt reaches from Lake Superior to the confines of the Red River valley, including the region of the headwaters of the Mississippi and its upper tributaries, as well as those of the Superior streams North of the pine region there is but a stunted growth of tamarack and dwarf pine In the north east are found the rugged elevations of the granite uplift of the shores of Lake Superior, rising to a considerable height, while in the north west the surface slopes away to the level prairie reaches of the Red River valley The surface elevation of the State varies from 800 to 2000 feet above sea level A short line of hills in the north east reaches the latter altitude, while only the valleys of the Red River, the Mississippi, and the Minnesota fall below the former

Geology and Soil —The geology has not yet been mapped out with the precision attained in other States The great central zone, from Lake Superior to the south western extremity of the State, is occupied by granitic and metamorphic rocks, succeeded, in the south-east, by narrower bands of later formation Within the great Azoic area lies the central watershed of the continent, from which the St Lawrence system sends its waters towards the Atlantic, the Mississippi towards the Gulf of Mexico, and the Red River of the North to Hudson s Bay These primordial rocks carry back the geologic history of Minnesota to pre Silurian times They form in the north east, in the neighbourhood of Lake Superior, an extremely rough and hilly country, but as they reach the central and south western portions of the State they for the most part disappear beneath the surface drift This central belt is succeeded, on the south and east, by a stretch of sandstone, partially the true red Potsdam and partially a similar but lighter coloured stratum, which some have proposed to designate the St Croix Sandstone Isolated beds of sandstone are found in various parts of the State The north western corner, stretching east from the Red River valley, is believed to be Cretaceous, but the great depth of drift and alluvium disturbed by no large rivers, prevents a positive conclusion The Lower Magnesian limestone underlies the extreme south eastern portion of the State, and extends along the west side of the Mississippi to a point a little below St Paul, thence it takes a course almost semicircular, and finally passes out of the State at the south western boundary The Trenton limestone occupies a large field in the south and south east, it comes to the surface in long irregular bands, and an island of it underlies the cities of Minneapolis and St Paul with the adjacent districts The Galena limestone, the Masquoketa shales, the Niagara limestone, and the rocks of the Devonian age in turn prevail in the other counties of the south and east, while the existence of the St Peter sandstone would scarcely be known but for its outcropping along the bluffs of the Mississippi, and at the famous waterfall of Minnehaha From these various formations numerous kinds of stone valuable for building purposes are obtained The grey granite of St Cloud is extremely hard and enduring The Lower Magnesian furnishes two especially handsome building stones,—the pink limestone known as Kasota stone, and the cream coloured stone of Red Wing, both easily worked, and hardening by exposure to atmospheric changes Naturally, from its location underneath the principal cities of the State, the Trenton limestone is the most widely used Sand suitable for glass making, and argillaceous deposits abound The clays which make up so large a portion of the surface drift of the State are almost wholly of glacial origin Overlying the deposits of sand, gravel, boulders, and clay is, in most portions of the State, a sandy loam, very finely divided, rich in organic matter, deep brown or black in colour, and of the greatest fertility It is this soil which has given to the State its reputation for productiveness Its depth varies from 2 to 5 feet in various parts of the State, and it has been described by Dr Owen as "excellent in quality rich as well in organic matter as in those mineral salts which give rapidity to the growth of plants, while it has that durability which enables it to sustain a long succession of crops "

Rivers and Lakes —The State holds a unique place in the great water systems of the continent The Mississippi which takes its rise north of the centre of the state in Lake Itaska and its contributory lakelets leaves the state limits a great river, half a mile wide, and from 5 to 20 feet deep It drains with its tributaries all the southern and central portions and a large area of the northern part of the State It is navigable as far as St Paul, and at Minneapolis the falls of St Anthony afford unrivalled facilities for manufacturing Of the many affluents of the Mississippi the most important is the Minnesota, which after a course of about 440 miles flows into the main stream at Fort Snelling 3 miles above St Paul The source of the Minnesota is but 1 mile from Lake Traverse, the origin of the Red River of the North, and it is navigable during the high water season for about 238 miles Its principal tributaries are the Blue Earth, Chippewa, Redwood, Lac qui Parle, and Pomme de Terre The Red River system drains the north western part of the State, and its waters finally pass into Hudson's Bay, as also do those from the country drained by streams flowing to the Rainy Lake river and the lakes along the northern boundary line East of this lies the region tributary to Lake Superior and the St Lawrence system This comprises an area within the State estimated at 9000 square miles Its principal river is the St Louis There are altogether about 2796 miles of navigable water in Minnesota

The number of lakes is estimated at seven thousand They are of all sizes and are found chiefly in the northern two thirds of the State They have been classified geologically into glacial or drift lakes, fluviatile or river lakes occupying basins on river courses, and lakes having rock basins either scooped out by the action of glaciers or formed by the relative position of different geological formations By far the greater number give evidence of glacial action in their origin They abound over the region most deeply covered by the surface drift, and are especially prevalent in morainic districts, forming the southern fringe of the lacustrine area of North America With the melting of the ice sheet which once overspread Minnesota its innumerable lakes came into existence, and the gentle acclivity of its slopes, precluding rapid erosive action, has tended to give permanence to the depressions constituting their basins The census returns give 4160 square miles of water surface within the State Most of the lakes are exceedingly picturesque in their surroundings Forests skirt their shores, which are seldom marshy, and their waters abounding in various kinds of fish, are clear and cool Besides the sanitary advantages afforded by the lakes, as supplying places for recreation and delightful summer resorts, they affect the climate to some extent tempering the extremes commonly experienced in northern latitudes The fact that many of the lakes are gradually drying up must be explained by agricultural operations The largest lakes exclusive of Superior lying wholly or in part in Minnesota are as follows —Lake of the Woods, 612 square miles, Red 342 Mille Lacs, 198, Leech, 194 Rainy, 146, Winnibigoshish, 78 and Vermilion, 63

Flora and Fauna —The flora and fauna present no marked differences from those of other States in the same latitude In a partial list of the birds of Minnesota two hundred and eighty one species are enumerated Of winter birds fifty two species have been classified, twenty three of them being permanent residents

Climate —The State lies so far north as to have a low mean annual temperature and so far inland as to have the characteristic continental climate Its elevation above sea level gives an agreeable rarefaction to the atmosphere and makes the prevalence of fogs and damp weather unknown Between June and January there is an annual variation from the summer heat of southern Ohio to the winter cold of Montreal The winter, usually commencing in November and continuing till near the end of March is not a period of intense continued cold but is subject to considerable variations As a rule, the comparative dryness of the atmosphere neutralizes the severest effect of excessive cold The snowfall is extremely light during most of the winter, but as spring approaches precipitation becomes greater, and there are frequently heavy snowfalls in February and March The change from winter to summer is rapid vegetation sometimes seeming to leap into full and active growth within the space of a few weeks The summer months bring days of intense heat but, with comparatively rare exceptions, the nights are deliciously cool Hot days and cool nights make the ideal weather for a good wheat crop, and the forcing heats of summer produce in luxuriant growth the vegetable life which belongs to the middle States The Smithsonian chart assigns to Minnesota an average temperature for the hottest week in summer of from 85° to 90°, and for the coldest week in winter from 10° to 20° below zero The mean annual average for all below 47° of latitude it gives as 40 Observations at St Paul extending over a period of more than thirty five years, show the following mean temperatures —spring 45° 6, summer, 70° 6, autumn, 40° 9 winter 16° 1 average 44° 6 The average annual rainfall is about 25 5 inches While this is not large, it is so distributed as best to subserve the purposes of vegetable growth No moisture is lost in superfluous spring and autumn rains, or in the cold and non producing part of the year the precipitation, which in winter is less than 2 inches, increasing to about 12 for the summer To the season of vegetable growth belong 70 per cent of the yearly measures of heat 76 per cent of the rainfall, and 76 per cent of the atmospheric humidity The prevailing winds are from the south or south east In 1880 rain or snow fell on 150 days, and in 1881 on 167 It is evident that the causes which mitigate the actual severity of the climate as felt, which produce so large a number of clear days, and which forbid the continued presence of a large amount of moisture in the atmosphere are those which render a climate healthful in the highest degree Minnesota has been for many years a favourite resort for invalids The curative properties of its climate are especially marked in the case of pulmonary complaints

Agriculture —The leading industry of the State is agriculture The character of the surface soil varies in different parts of the State with the character of the underlying strata The fertile land comprises about three fourths of the entire area of the State The drift soil proper of the south and centre, including the Minnesota valley and the greater part of that of the Mississippi, contains silica and calcareous matter, and is interspersed with alluvial river bottoms The limestone soil, in which there is a large calcareous element, lies chiefly on the western slope of the Mississippi The Red River valley consists of an argillaceous mould, rich in organic deposits Around Lake Superior, wherever arable land is to be found, it is marked by a rich trap soil North of the central fertile area, and in the neighbourhood of the sources of the Mississippi, is much swampy land, susceptible of easy drainage, with a large tract of sand and other drift detritus, unfavourable to production Maize and potatoes flourish, and the uplands, which support hardwood ridges, are suited to general agriculture To the extreme north the surface, while indicating mineral wealth, is utterly unfit, except in occasional isolated areas, for purposes of tillage

Wheat has hitherto been the staple product of the State Soil and climate are such as to ensure a large average yield, while the superior quality of the grain has given it a wide reputation The other cereals are also cultivated with success The tendency to diversify agriculture, especially in the southern part of the State, has been stimulated by several partial failures of the wheat crop, the locust invasions, and the competition of the farther north west

The area of the State includes 39,791,265 acres surveyed, 10,968,575 acres not surveyed and 2,700,000 acres of lake surface The total sales of public and railroad lands in 1879 and 1880 were not far from 4,000,000 acres It is estimated that the aggregate of lands yet undisposed of, three fourths of which may be profitably cultivated, is nearly 20,000,000 acres, exclusive of the lands belonging to the State White Earth Indian reservation has thirty six townships of prairie and timber land and Red Lake reservation contains 3,200,000 acres

Forestry —A special census bulletin estimates the amount of merchantable white pine standing, May 31, 1880, as amounting in all to 6,100 000,000 feet The entire cut for the census year 1880 was 540,997 000 feet Of hardwood forest 3,840,000 acres remain, capable of yielding 57,600,000 cords of wood

Every encouragement is afforded, both by the railway corporations and the State, to tree planting on the prairies A quarter section is given to any one who will plant and keep in good condition 40 acres of timber for eight years In 1880 there were planted 25,331 acres of trees, exclusive of those bordering highways and the windbreaks along the railroad lines

Manufactures —The manufactures of Minnesota are yet in their infancy The abundant water power of the State, its proximity to the coal fields of Iowa its superior transportation facilities, and the large demand for manufactured commodities are however, rapidly developing this branch of industry The most important industries are the manufacture of flour and that of lumber The former naturally established itself in a State of immense wheat yield and abundant water power It received its greatest stimulus from the invention and adoption of the middlings purifying process, which produces the highest grade of flour, and to which the hard spring wheat of Minnesota is especially adapted Among other manufacturing industries actively prosecuted are the making of brick, pottery, stoneware, and agricultural implements, and also meat packing

Commerce —The geographical position of Minnesota gives it extensive commercial interests Two continental waterways terminate within the State The Mississippi affords continuous navigation to European ports during eight months of the year From Duluth numerous lines of vessels traverse the chain of great lakes and transport the products of the west to the eastern seaboard Three great transcontinental railway lines are connected more or less directly with the railroad system of the State Twelve lines of railway from every part of Minnesota converge at the contiguous cities of St Paul and Minneapolis, and three great trunk lines from these centres to Chicago secure the advantages of a lively competition

Education —The common school system is supported by land grants, a local tax, and a State tax The superintendent of instruction is appointed by the governor County superintendents are chosen by popular vote Common school districts have boards of three trustees each Six directors are appointed for independent districts The permanent fund in 1881 was $4,850,000, and the current fund $260,835 The State university, located at Minneapolis, is governed by a board of regents, consisting of the governor of the State, the superintendent of public instruction, the president of the university, and six others, both sexes are admitted, and tuition is free The State supports three normal schools Forty two academies and six colleges are sustained by denominational or private enterprise

Administration —The departments of Government are, as in all the States, the legislative, the executive, and the judicial The State contains seventy-eight counties, of which some are still subject to change of boundary From these are elected by districts forty seven senators and one hundred and three members of the House of Representatives The State officers are a governor, lieutenant governor, secretary of state, treasurer, and attorney-general all elected by the people The term of office is two years

The governor has power to veto separate items of a money bill The judiciary is elective, and the term of office seven years The State requirements for citizenship are residence in the United States one year, in the State four months, and in the election district ten days preceding an election Women are allowed to vote for school officers and upon questions relating to the management of schools, and are also eligible to such offices No county can contain more than 400 square miles The legislature meets biennially Extra sessions may be called, but no session can exceed sixty days in length Under the last apportionment the State is entitled to five representatives in the national Congress

The annual valuation of property for 1882 as equalized by the State board, gives the personal property as $79 219,445, the real estate $242,938,170 This represents a total actual value of not far from $750,000,000

While Minnesota was still a Territory, but after it had adopted a State constitution, an amendment was added to the constitution authorizing the issue of a large amount of bonds in aid of railway construction Shortly afterwards, the companies having failed to fulfil their contracts and defaulted payment, the State foreclosed its mortgage on the lands, franchises, &c , of the roads, and turned them over to other companies By another amendment to the constitution, the payment of the bonds was made contingent upon the result of a popular vote Several proposals having failed to receive this sanction, the necessity for it was removed in 1881 by a decision of the supreme court, declaring the amendment unconstitutional The legislature immediately met, accepted a plan of settlement proposed by the bondholders themselves, and over $4,000,000 worth of new bonds were issued in exchange for the old For the payment of the principal and interest of these the people have voted (November 1882) to set aside as a sinking fund the proceeds of 500,000 acres of land belonging to the State internal improvement fund the deficit to be paid out of the tax on railroad earnings These bonds include all the State debt except about $200,000 A tax of 3 per cent imposed on the gross earnings of all railroads within the State will soon meet all expenses except provision for educational penal, and charitable institutions

Population —The population of the State was 6077 at the census of 1850, 172,023 in 1860, 439,706 in 1870, and 780 773 (419,149 males and 361,624 females) in 1880 According to the last census 299,800 whites had been born in the State, and of the 267 676 foreign born inhabitants of the State 107 770 came from Scandinavian countries and 68 277 from the United Kingdom and the British colonies, while 77,505 acknowledge the German as their native tongue The increase of population in the State for the last decade of years alone was 75 per cent The most important cities are St Paul the capital, and Minneapolis, with 41 473 and 46,887 inhabitants respectively in 1880 Winona had 10,208 and Stillwater 9055

History —Missionary efforts and the trading spirit first induced white men to venture as far into the unexplored north west as the boundaries of what is now the State of Minnesota The earliest accounts of its natural features and native tribes appear in the Jesuit writings The ‘Relations of 1670 71 allude to the Sioux or Dakotas In 1678 a company was formed for trading with this tribe Du Luth was leader of this expedition, and later on went from Lake Superior to the Mississippi by canoe But the first published account is that of Louis Hennepin, a Recollect monk, who, in 1680, visited the falls of St Anthony, and gave them their name, from that of his patron saint For a century the only visitants of the wild region were a few missionaries and a number of fur traders who found the profit of the journey to more than counterbalance its perils and hardships To the latter class belong Perrot, who reached the Mississippi by way of the Fox and Wisconsin in 1684, and founded at Lake Pepin the first trading post in the State, and Le Sueur, a Canadian, who ascended the great river from its mouth, and established another post above Lake Pepin Captain John Carver the explorer of the country of the upper Mississippi, visited the falls of St Anthony in 1766 being the first British traveller who reached the spot On March 20, 1804, Upper Louisiana was organized, consisting of Arkansas Missouri Iowa, and a large portion of Minnesota From this time onwards the progress of exploration was rapid, and settlement followed in its train The first really extensive exploration of any large part of what is now Minnesota was made between 1817 and 1823, by Major S H Long, of the United States engineer corps, in command of a Government expedition About the same time the Red River received its first visitant Thomas Douglas earl of Selkirk an Englishman of eccentric character, went, in 1817, to what is now Winnipeg by way of York river Having been struck with the agricultural possibilities of the region about the Red River of the North, he induced a colony of Swiss farmers to settle there These were disappointed in the country, and unused to the severity of the climate, so that they finally removed to the vicinity of St Paul and contributed to the earliest development of the agricultural industry of the State In 1821 Colonel Snelling built at the junction of the Minnesota and Mississippi rivers a stronghold which he named Fort St Anthony The name was changed to Fort Snelling in his honour, in 1824, and the fort is still an important post as a base of supplies for the newer north-west The first steamboat made its appearance at the head of navigation in 1823 The settlement of St Paul, one of the oldest towns as well as the capital, is commonly dated from 1846, at which time there were a few shanties on its site Population now began to arrive in constantly increasing numbers, and on March 3, 1849, a bill passed Congress for organizing the Territory It was proposed at one time to name it Itasca, but the name Minnesota, meaning, "sky tinted water, and originally applied to the river bearing that title, was finally retained The western boundary of the territory was fixed at the Missouri river The population was but 4057, the largest town had but a few hundred inhabitants, and a large part of the soil of the State still belonged to the Indians But progress now began in earnest A constitution was adopted in 1857, and on May 11, 1858, Minnesota was admitted as a State, with a population, according to the last Territorial census, of 150,037

One of the first acts of the new State was the issue of the railroad bonds noticed above Soon after came the civil war Within two months of Lincoln s first call for troops the first Minnesota regiment, over one thousand strong, was mustered into service By August of 1862 ten regiments had been called for and furnished In all, the State supplied to the armies of the Union 25,052 men, or about one seventh of its entire population at the outbreak of the war

In the meantime there occurred in 1862, the horrible outbreak known as the Sioux massacre Settlements were cut off isolated settlers murdered, and even a strong post like Fort Ridgely was attacked The outbreak spread over a large portion of the State, several severe engagements were fought, and it was not until the State had a thoroughly equipped military force ready for the campaign that the Indians begun to flee or to give themselves up By this time over 700 persons had been murdered, 200, chiefly women, taken captive, eighteen counties were ravaged, and 30,000 people were homeless The property loss was not less than $3,000,000

During these local and national disturbances the material prosperity of the State was unabated Notwithstanding the heavy cost of the civil war and the Sioux massacre, the census of 1865 showed a population of 250,099 Railroad construction began to be energetically carried forward, in 1870 329 miles were made and 1096 miles were in operation, a road to Lake Superior was completed, and the Northern Pacific was fairly under way In 1873 76, and to some extent in 1877, successive visitations of locusts destroyed the crops of the south western counties The sufferers were relieved by the State, and no repetition of the scourge has since been experienced (J G P)

MINNOW (*Leuciscus phoxinus* or *Phoxinus lævis*) is the smallest British Cyprinoid, readily distinguished by its very small scales It is abundant in rivers, brooks, and lakes, always swimming in schools, and shifting its ground in search of food, which consists of every kind of vegetable and animal substance It ranges from southern Europe to Scandinavia, and from Ireland into north eastern Asia, in the Alps it attains to a higher altitude than any other Cyprinoid, viz, to nearly 8000 feet Its usual size varies between 2 and 3 inches, but in suitable localities, especially in Germany, it is known to reach a length of from 4 to 5 inches The colours vary with age and season, a series of dark spots or cross bands along the sides is always present, but the males assume in summer a nuptial dress of scarlet or purple on the lower parts of the head and body The minnow is used as bait, it can also be introduced with facility and with great advantage into ponds in which there is otherwise a scarcity of food for more valuable fishes, such as trout, perch, and pike

MINO DI GIOVANNI (1431–1486), called DA FIESOLE, was born at Poppi in the Casentino in 1431 He had property at Fiesole, whence his usual name Vasari's account of him is very inaccurate and full of contradictions Mino was a friend and fellow worker both with D da Settignano and Matteo Civitale, all three being about the same age There is considerable similarity in their works showing mutual influence Mino s sculpture is remarkable for its gem like finish and extreme delicacy of detail, as well as for its spirituality and strong devotional feeling No other sculptor portrayed the virginal purity of the Madonna or the soft infant beauty of the Divine Child with greater tenderness and refinement Of Mino's earlier works, the finest are in the duomo of Fiesole, the altarpiece and tomb of Bishop Salutati, executed about 1464 In the Badia of Florence are some of Mino's most important sculptures—an altarpiece, and the tombs of Bernardo Giugni, 1466, and the Margrave Hugo, 1481—all sculptured in white marble, with beautiful life sized recumbent effigies and attendant angels The pulpit in Prato cathedral, finished in 1473, is very delicately sculptured, with bas reliefs of great minuteness, but somewhat weakly designed Soon after the completion of this work Mino paid a visit of some years to Rome, where he executed several fine pieces of sculpture, such as the tomb of Pope Paul II (now in the crypt of St Peter's), the tomb of Francesco Tornabuoni in S Maria Sopra Minerva, and a beautiful little marble tabernacle for the holy oils in S Maria in Trastevere There can be little doubt that he was also the sculptor of several of the very lovely monuments in S Maria del Popolo, especially those in the sacristy of Bishop Gomiel and Archbishop Rocca, 1482, and the marble reredos, also in the sacristy, given by Pope Alexander VI Some of Mino's portrait busts and delicate profile bas reliefs are preserved in the Bargello at Florence, they are full of life and expression, though without the extreme realism of Verrocchio and other sculptors of his time He died in 1486

See Vasari Milanesi's ed , 1878 82, Perkins, *Italian Sculptors* Winckelmann and D Agincourt, *Storia della Scultura*, 1813

MINOR See INFANT

MINORCA See BALEARIC ISLANDS

MINORITES See FRANCISCANS

MINOS, a legendary king of Crete, in whom both historical and religious elements are united The historical element lies in the fact that an early civilization and mari time power had its seat in Crete The Phœnician inter course played a great part in developing this island state, and Minos is sometimes called a Phœnician The name Minoa is often found where Phœnician influence was strongest, *e g*, at Megara The laws and constitution which existed from a very early time in Crete were attributed to Minos, to whom they were revealed by Zeus After his death he became the judge of the dead, he is one of the forms assumed by the old conception of the first man, who is after death king and god among the dead It is therefore highly probable that the name Minos is the Greek form of the original *Manva*, *i e*, "endowed with thinking," which is seen in the Hindu Manu and the Germanic Mann As in all other heroized forms of the god of the dead, there is both a terrible and a wise and beneficent side in the character of Minos Cretan legends described him as the wild huntsman of the forests and mountains, the lover of the nymphs, though his love means death to them His death is localized in the far west, in the land of sunset, his grave was shown at Camicus near Agrigentum, attached to a temple of Aphrodite He pursued Dædalus thither, and the daughters of Cocalus, the king of Agrigentum, killed him by pouring boiling water over him in the bath, an obvious myth of the sun dying in the sea Minos, the god of the dead, is, according to the usual rule, the sun god, who goes to illumine the dead when he dies on the earth His wife is Pasiphae, the moon goddess, who had an oracle by dreams at Thalamæ in Laconia The union of the sun and the moon the bull and the cow, gave rise to many quaint and ugly legends Pasiphae loved the bull of Minos, was aided by the stratagem of Dædalus, and gave birth to the Minotaur, half bull and half man The Minotaur is one of those monstrous forms which were suggested to the Greek fancy by the quaint animals common in Oriental art. It was shut up in the LABYRINTH (*q v*), which was constructed by the skilled artist Dædalus Now a son of Minos named Androgeus had been killed by the Athenians, and Minos as a punishment required that seven Athenian youths and seven maidens should be sent every ninth year and given up to the Minotaur to be devoured When this sacrifice took place for the third time Theseus came as one of the hostages, and slew the Minotaur with the help of Ariadne Throughout these legends we see the close relation of Minos to the Phœnician sun god Melkarth, and perceive the way in which different places where Phœnician influence can be traced, Athens, Sicily, &c, are brought together in religious myths

MINOTAUR See MINOS

MINSK, a western government of Russia, is bounded by Vilna, Vitebsk, and Moghileff on the N and E, and by Tchernigoff, Kieff, Volhynia, and Grodno on the S. and W, and has an area of 35,175 square miles The surface is undulating and hilly in the north west, where a narrow plateau and a range of hills of the Tertiary formation runs to the north east, separating the basin of the Niemen, which flows into the Baltic, from that of the Dnieper, which sends its waters into the Black Sea The range, which averages from 800 to 1000 feet, culminates in Lysaya Gora (1129 feet) The remainder of the province is flat, 450 to 650 feet above the sea level, covered with sands and clays of the glacial and post glacial periods Two broad shallow depressions, drained by the Berezina and the Pripet, cross the province from north to south and from west to east, and these, as well as the triangular space between them, are covered with immense marshes (often occupying 200 to 600 square miles), numberless ponds and small lakes, peat-bogs, downs, and moving sands, as well as with dense forests This country, and especially its south western part, is usually known under the name of Polyesie ("The Woods") Altogether, marshes take up 15 per cent and marshy forests no less than 55 per cent of the entire area of the province (60 to 71 per cent in several districts) The forests, however, consist of full-grown trees in the higher districts of the north west only, those which occupy the marshy ground consisting of small and stunted pine, birch, and aspen The climate of the Polyesie is harsh and extremely unhealthy, malarias and an endemic disease of the bulbs of the hair (*koltun, plica Polonica*) are the plagues of these tracts, the evil being intensified by the dreadful poverty of the population Communication is very difficult The railway from Poland to Moscow has, so far as Minsk is concerned, taken advantage of the plateau above mentioned, but still it has to cross the broad marshy depression of the Berezina A successful attempt was recently made to drain the marshes of the Polyesie by a system of canals, and more than 4,500,000 acres have thus been rendered suitable for pasture and agriculture Two great tributaries of the Dnieper, the Berezina and the Pripet, both navigable, with numberless subtributaries, many of which are also navigable, are the natural outlets for the marshes of the province The Dnieper flows along its south eastern border for 160 miles, and the Niemen on the north western for 130 miles The affluents of the Baltic, the Duna (Dwina), and the Vistula are connected by three canals with tributaries of the Dnieper The population of the province (1 183,200 in 1873) may be estimated at about 1,350,000, mostly White Russians (67 per cent), there are also Poles (about 11 per cent), especially in the western districts, Jews (more than 10 per cent), Little Russians (5 per cent), and Russians (2 per cent) About 70,000 are considered to be Lithuanians, there are also 4000 Tartars, whose presence can be traced to the raids of their ancestors on Lithuania in the 13th century, and about 2000 German agriculturists who settled in last century

The chief occupation of the inhabitants is agriculture, which is, however, very unproductive in the lowlands, in the Polyesie the peasants rarely have pure bread to eat Only 23 8 per cent of the area is under crops, the average yield being 1,600,000 quarters of corn and 1,170,000 quarters of potatoes. Cattle breeding is very imperfectly developed, the meadows being marshy throughout the lowlands. Hunting and bee keeping are sources of income in the Polyesie, and fishing gives occupation to about twenty thousand persons. The chief source of income for the inhabitants of the lowlands is the timber trade. Timber is floated down the rivers, and tar, pitch, various products of bark, potash, charcoal, and numerous sorts of timber ware (wooden dishes, &c.) are manufactured in villages to a great extent; and shipbuilding is carried on along the Dnieper, Pripet, and Niemen. Shipping is also an important source of income, owing to the traffic on the canals and rivers of the province. In 1877 560 boats and 1120 rafts with 170,000 cwts. of cargo left the banks of the Berezina and Pripet; and the traffic on the Dnieper and Niemen was nearly as great. The industrial arts are almost entirely undeveloped. There are, however, several distilleries and tanneries; and woollen stuffs, candles, tobacco, and sugar are manufactured to a limited extent. Corn is exported from the western districts, but imported to the same amount into the southern parts; the chief export trade is in produce of forest industries. The province is crossed by two important railways, one of which connects Poland with Moscow, and the other Libau and Vilna with the provinces of Little Russia; the great highway from Warsaw to Moscow crosses the province in the south, and its passage through the Berezina is protected by the first class fortress of Bobruisk. Minsk is divided into nine districts, of which the capitals are—Minsk (43,500 inhabitants), Bobruisk (26,850), Borisoff (5650), close by the place where Napoleon I. crossed the Berezina on his retreat from Moscow, Igumen (2200), Mozyr (4200), Novogrodek (9000), Pinsk (18,000), Ryechitsa (4300), and Slutsk (17,200). The province is well provided with secondary schools, but primary education, especially in the Polyesie, is in a very backward state.

The country now occupied by the province of Minsk was, as far as historical records extend, an abode of Slavonians. That portion of it which was occupied by the Krivichi became part of the Polotsk principality and so of "White Russia"; the other portion, occupied by the Dregovichi and Drevlans, became part of the "Black Russia"; whilst the south western portion of it was occupied by Yatvyags or Lithuanians. During the 12th, 13th, and 14th centuries it was divided among several principalities which were incorporated with the great principality of Lithuania, and later were annexed to Poland. Russia took possession of this country in 1793. In 1812 it was invaded by the army of Napoleon I.

MINSK, the capital of the above province, is situated on the Svisloch, a tributary of the Berezina, at the junction of the Moscow and Warsaw and the Libau and Kharkoff railways, 465 miles by rail west from Moscow. It has 43,500 inhabitants, of whom one third are Jews of the poorest class; the others are White Russians, Poles, and Tartars (about 700). The manufactures are few and insignificant. Since the introduction of railways the commercial importance of the place, which formerly was slight, has begun to increase.

Minsk is mentioned in Russian annals in the 11th century under the name of Myen'sk or Menesk. In 1066 and 1096 it was devastated, first by Izyaslav and afterwards by Vladimir. It changed rulers many times until the 13th century, when it became a Lithuanian fief. In the 15th century it became part of Poland, but as late as 1505 it was ravaged by Tartars, and in 1508 by Russians. In the 18th century it was taken several times by Swedes and Russians. Russia annexed it in 1793. Napoleon I. took it in 1812.

MINSTREL. The "minstrels," according to Bishop Percy, "were an order of men in the Middle Ages who united the arts of poetry and music, and sang verses to the harp of their own composing, who appear to have accompanied their songs with mimicry and action, and to have practised such various means of diverting as were much admired in those rude times, and supplied the want of more refined entertainments." This conception of the "minstrel" has been generally accepted in England ever since Percy published his *Reliques of Ancient Poetry*, which he gave to the world as the products of the genius of these anonymous popular poets and harpers. The name has been fixed in the language by the usage of romantic poets and novelists; Scott's "last minstrel" and Moore's "minstrel boy" were minstrels in Percy's sense of the word. The imagination was fascinated by this romantic figure, and the laborious and soured antiquary Ritson argued in vain that nobody before Bishop Percy had ever applied the word minstrel to such an order of men, that no such order of men ever did exist in mediæval England, and that the historical English "minstrels," so-called, were a much less gifted and respectable class, being really instrumental musicians, either retainers or strollers.

The dispute between Ritson and Percy was partly a dispute about a word, and partly a dispute about historical facts; and there can be little doubt that Ritson was substantially right in both respects. The romantic bishop transferred to the mediæval English minstrel the social status and brilliant gifts of the Anglo-Saxon *gleoman* or *scóp*, and the French *troubadour* in the flourishing period of Provençal poetry. That the gleemen sang to the harp verses of their own composing, that some of them travelled from court to court as honoured guests, while others were important attached court officials, and all received costly presents, is a well attested historical fact. The household bard at Heorot in the poem of *Beowulf*, a man who bore many things in mind and found skilfully linked words to express them, was one of King Hrothgar's thanes; the gleeman of the *Traveller's Song* had visited all the tribal chiefs of Europe, and received many precious gifts, rings and bracelets of gold. The incidents in these poems may not be historic, but they furnish indubitable testimony to the social position of the gleeman in those days; a successful gleeman was as much honoured as a modern poet laureate, and as richly rewarded as a fashionable *prima donna*. Further, the strolling gleeman of a humbler class seems to have been respected as a non combatant; this much we may infer from the stories about Alfred and Anlaff having penetrated an enemy's camp in the disguise of gleemen, whether these stories are true or not, for otherwise they would not have been invented. The position of poets and singers in Provence from the 11th to the 13th century is still clearer. The classification of them by King Alphonso of Castile in 1273, by which time honourable designations were getting mixed, may help to determine the exact position of the English "minstrel." There was first the lowest class, the *bufos*, who strolled among the common people, singing ribald songs, playing on instruments, showing feats of skill and strength, exhibiting learned dogs and goats, and so forth; then the *joglars* or *joculatores*, who played, sang, recited, conjured, men of versatile powers of entertainment, who performed at the houses of the nobility, and were liberally remunerated; then the *trobadors*, or *inventores*, whose distinction it was to compose verses, whether or not they had sufficient executive faculty to sing or recite them.

If we compare these distinctions with Percy's definition of the minstrel, we see that his minstrel would have corresponded with the *joglar*, who also wrote his own songs and recitations. Now in the palmy days of Provençal song there were many professional joglars, such as Arnaut Daniel or Perdigo, who stood high among the most brilliant troubadours, and visited on terms of social equality with nobles and princes. But long before English became the court language the fashion had disappeared, and a new division of functions had been developed. In Chaucer's time the poet of society no longer sang his verses to harp or fiddle, or amused his patrons with feats of legerdemain; the king's *gestour* (teller of *gestes*) discharged the professional duty of amusing with witty stories; and the social position of the *joglar* had very much sunk. Ritson was perfectly right in saying that no English poet of any social position was a professional reciter to the harp of verses of his own composing. The Provençal joglar, travelling from court to court, combined our modern functions of poet, society journalist, entertainer, and musician. But about the time when the word "minstrel" came to be applied to him the English joglar was rapidly sinking or had already sunk to the social position of the modern strolling mountebank, travelling showman or music hall singer. And the word minstrel had had a separate history before it became synonymous (as in the *Catholicon Anglicum* of 1483) with *gesticulator*, *histrio*, *joculator*, and other names for strolling entertainers Derived from the Low Latin *ministralis*, it was originally applied to those retainers whose business it was to play upon musical instruments for the entertainment of their lords In Chaucer's *Squire's Tale*, the "minstralles" play before King Cambuscan as he dines in state "biforn him at the bord deliciously,' and the "loude minstralcye" precedes him when he rises and withdraws to the ornamented chamber,

> Ther as they sownen diuerse instrumentz,
> That it is lyk an heuen for to here

But even in Chaucer's time there were less respectable musicians than those of the king's household—strolling musicians, players on trumpets, clarions, taborets, lutes, rebecks, fiddles, and other instruments These also were known by the generic name of minstrels, whether because many of them had learnt their art in noble households before they took to a vagabond life, or because the more respectable of them affected to be in the service or under the patronage of powerful nobles, as later on companies of strolling players figured as the "servants" of distinguished patrons All the allusions to minstrels in literature from Langland's time to Spenser's point to them as strolling musicians Some of them may have sung to the harp verses of their own composing, and some of them may have composed some of the ballads that now charm us with their fresh and simple art, but the profession of the "minstrel," properly so called, was much less romantic than Bishop Percy painted it It was not merely "the bigots of the iron time that "called their harmless art a crime", in a repressive Act passed by Henry IV they appear with "westours, rymours, et autres vacabondes" among the turbulent elements of the community

In a passage in Malory's *Morte Darthur*, the word minstrel is applied to a personage who comes much nearer the ideal of the Provençal *joglar* When Sir Dinadan wished to infuriate King Mark, he composed a satirical song, and gave it to Elyot a harper to sing through the country, Tristram guaranteeing him against the consequences When King Mark took him to task for this, the harper's answer was, "Wit you well I am a minstrel, and *I must do as I am commanded of these lords that I bear* the arms of And because he was a minstrel King Mark allowed him to go unharmed The service done by Elyot the harper in the old romance is a good illustration of the political function of the itinerant mediæval *joculator*, but even he did not sing verses of his own composing, and he was not a "minstrel" in the sense in which the word was used by romantic poets after the publication of Percy's *Reliques* (W M)

MINT The mint is the place where the coinage of a country is manufactured, and whence it is issued by sovereign authority, under special conditions and regulations The privilege of coining has in all ages and countries belonged to the sovereign, and has, in England at least, been rarely delegated to any subject, and in any case in a restricted form, the crown always reserving the right of determining the standard, denomination, and design of the coins

At a very early stage of civilization it was found necessary to have some definite medium of exchange, in order to avoid the great inconvenience arising from the system of payment in kind, which was the primitive and natural method It was not long before metal came to be used as such a medium, probably from its durability and portability, and in the case of gold and silver on account of their intrinsic value The less liable the value of a metal is to change the better is it suited for a standard of value

Though historians assure us that metals were found in Britain at a very early period, there does not appear to be any evidence that the mines were worked until considerably later than the time at which the use of metal as a medium of exchange was introduced It is probable therefore that the metals for exchange were imported into Britain long before the native mines were developed

The metals chiefly used were silver and brass, which were at first simply exchanged by weight for commodities of all kinds As commercial transactions became more numerous and more complicated, this system of payment grew troublesome, and it was found convenient to divide the mass of metal into small parts, which soon took the form of rough coins But the principle of payment by weight was retained through many centuries, and is perpetuated, though in name only, in the word "pound"

Records of attempts to organize the coinage of England are found as far back as the Anglo Saxon period, and it is known that on the dissolution of the Heptarchy the mints were regulated by laws framed in the witenagemot The first monarch who appears to have dealt successfully with the organization of the coinage was Athelstan, who framed laws for the regulation of the mints, and appointed officers whose titles and duties are then first recorded The only officers connected with the coinage of whom mention is found before this time are the "moneyers," who appear to have been alone responsible for the manufacture of the coin, but it is probable that even then there existed some officer who had authority over them In early Saxon and Norman times the number of moneyers was considerable, mints being established in almost every important town, as might be expected at a period when communication between distant places was extremely difficult They appear to have been the officers who actually performed the work of making the coin, the mint master in later times contracting with them, at a high rate, for the work They were responsible for the purity and perfection of the coins produced, as appears from the fact that it was they who were punished (as traitors) in the case of any deficiency in weight or fineness They had prescriptive rights in the coinage, and in modern times (even so late as 1850) claimed to have corporate privileges, but it is clear, on the authority of Ruding, that they never were a "corporation" separate from other officers of the mint[1] The number of mints was greatly reduced after the Norman Conquest, but continued to be considerable until the reign of Richard I, when the work of coining for the whole kingdom was concentrated in the mint in the Tower of London Only one provincial mint (Winchester) remained till a later date

An important reorganization of the coinage took place in 1325 under Edward II, the regulations then framed for the manufacture and issue of the coins forming the basis of those still in force The principal officers under these regulations were—master, warden, comptroller, king's assay master, king's clerks, and cuneator The office of cuneator was one of great importance at a time when there existed a multiplicity of mints, since he had the sole charge of all the dies used not only at the mint in the Tower of London but also in the provinces He chose the engravers and presented them to the barons of the exchequer in order that they might take the oath of fidelity, he superintended their work, and was generally answerable for the perfection of the dies before they were issued for use in the various mints of the country The office, which was hereditary, ceased to exist when the provincial mints were suppressed In its place was instituted the office of clerk of the irons, whose functions were more limited, and were not hereditary. This office was only recently abolished.

---

[1] Among the special privileges which they undoubtedly enjoyed was exemption from local taxation, as appears in a writ of Henry III, which commands the mayor of London not to disturb them "by exacting tallages contrary to their privileges" Sometimes also houses were allowed to them rent free

In the Middle Ages an important duty devolving on the officers of the mint was the collection of the seigniorage which was levied on the coining of money, not only for the purpose of covering the expenses of minting, but also as a source of revenue to the crown which the sovereign claimed by virtue of his prerogative. In former times the collection of the seigniorage was entrusted to the warden, who also superintended the manufacture of the coins, so far as to ensure the proper relations between the moneyers on the one hand and the state on the other. He does not appear, however, to have had any responsibility with regard to the fineness and weight of the coins.

The king's assay master was specially charged with all matters relating to the accuracy of the standard. The officer next in rank to him was the comptroller, who presented annually to the barons of the exchequer a report of all the gold and silver money struck in the kingdom during the year. These reports, which were always written upon parchment, constitute the chief mint records. The king's clerk exercised a general superintendence and kept an account of all the mint transactions. As the work of the mint became more extensive and more complicated, other officers were added, such as the surveyor of the meltings, surveyor of the money presses, and many others.

The present arrangements with regard to the officers of the mint were made in 1870, when several important changes took place in the mint establishment. Up to that time there had been two controlling officers,—the master, who in some instances was selected on account of distinguished scientific attainments (as in the cases of Sir John Herschel and Professor Graham), and the deputy master and comptroller. A careful inquiry, however, having led to the conclusion that the control of the mint might with advantage be concentrated in the hands of a single officer of experience in the conduct of public business, it was decided, on the death of Professor Graham, to entrust the actual administration of the department to the deputy master,—the office and title of master of the mint being held by the chancellor of the exchequer for the time being, without salary. At the same time the services of a scientific officer were secured, by the appointment of a chemist of the mint. The coining and die department and the melting department were united under the name of the operative department, and placed under a single superintendent. The first deputy master appointed under the new regulations was the Hon. C. W. Fremantle, C.B., to whom the public are indebted for a series of *Annual Reports* which have given a new and increased interest to the subject of the coinage, and may be said to constitute in themselves a mint literature.

The actual operations of coining in early times were few in number and simple in character. The metals forming the alloy were melted together in the proportion necessary to bring them to the required standard, and the alloy thus obtained was cast into bars, which were reduced by hammering to the requisite thickness. They were then cut with shears into pieces more or less regular in size and form, roughly annealed, and finally impressed with the prescribed device by a blow with a hammer.

The last named appears to have been the only part of the process which was performed with any great amount of care. The blank piece was placed by the hand upon a die fixed into a block of wood having a large heavy base to resist the oscillation caused by the blow; the die on which was engraved the device for the reverse of the coin was then placed upon the upper side of the blank and held by means of a holder, round which was placed a roll of lead to protect the hand of the operator while heavy blows were struck with a hammer by an assistant workman. One of the earliest improvements in coining was the introduction of a tool in shape resembling a pair of tongs, the two dies being placed one at the extremity of each leg. This avoided the necessity of readjusting the dies between successive strokes of the hammer, and ensured greater accuracy in the impression. It was long before the system of coining by hand was superseded by the coining press, or mill, which, even after its first introduction, was only very slowly adopted. Several attempts were made to introduce machinery for coining before it was brought into active use, the objection to it being its great expense. The mill and screw were finally introduced into the mint under Charles II., when many improvements were also made in the preliminary operations. Steam power was first applied in 1810, when the vacuum screw press was introduced. In 1839 Uhlhorn invented the lever press, which still remains in use.

The subject of the design on coins, besides being interesting both from an artistic and an historical point of view, becomes very important when it is remembered that it is the impression of the coin with the authorized device which makes it legally current. The artistic merits of the design of the early Greek coins are well known, and prove that the dies from which the coins were struck must have been engraved with much skill and care. The form of the coins before being stamped was at first merely that of natural rounded nuggets of gold, or of the silver gold alloy known as *electrum*. Such coined nuggets of gold are still to be found among the hill tribes of India. Simple nuggets were afterwards replaced by roughly fashioned masses like half bullets, a form which rendered it easy to impart high relief to the obverse and comparatively low relief to the reverse of the coins. The early British coins[1] had for their prototype the gold "stater" of Philip of Macedon, but the design of this beautifully finished coin was so roughly imitated by a succession of British copyists that ultimately the wreath round the head of the monarch alone survived, and that in a scarcely recognizable form. It is not only in the early British coins that the influence of classical art may be seen, for it is very evident in some of the present day, the most notable instances being the reverse of the bronze coinage, and the beautiful design of St George and the dragon by Pistrucci, which is still used as an alternative design for the sovereign. It has been ascertained that the impressions on the reverse of very early Greek coins were produced by the rough surface of the anvil or the nail head on which they were placed, while the obverse was struck with the die. A little later the device on the reverse of the coins was obtained by placing the blank piece on small points of metal arranged in geometrical forms which caused corresponding indentations on the coins when struck with the hammer. The beauty and accuracy of design on coins gradually increased as art and manual skill developed, and probably culminated at the period of the Renaissance.

Although it has been the custom since the time of the Saxons to stamp coins with the head of the reigning monarch, it does not appear that any attempt at actual portraiture was made in England until the reign of Henry VII., who, "about the eighteenth or nineteenth year of his reign, did make a great alteration in the form of his coin, upon which his head was now represented in profile, and with a good resemblance of his other pictures."[2] Since then much care seems to have been taken to stamp the coins with a true likeness of the monarch. In most cases the heads bear a striking resemblance to the portraits drawn by the great artists of the respective periods, and were, indeed, generally designed by artists of eminence. Some of the Milan coinage of Louis XII. is said to have been designed by Leonardo da Vinci, and similar work is attributed to Benvenuto Cellini.

---

[1] See Evans, *Coins of the Ancient Britons*.

[2] See Martin Folkes, *Tables of English Silver and Gold Coins*.

In very early times the silver coins were equal in weight and in tale, each penny weighing 24 grains or 1 pennyweight. The amount now denominated a pound was a pound weight of standard or sterling silver. This principle was in fact, however, not strictly adhered to, the coins frequently falling below the standard of weight. This deviation may possibly have arisen from the imperfection of the methods of manufacture, but Ruding (*Annals of the Coinage*) considers it to have occurred from design, as the deficiency in weight was sometimes made a source of profit. The deviation from the standard weight permitted by law, now called the "remedy," and anciently called the "shere," was taken advantage of to a large extent, so that the coins suffered considerable diminution, particularly when, as frequently happened, they were also "clipped" as soon as they were issued. When these coins were called in they were taken by weight and not by tale, so that the possessors suffered considerable loss. In later times the great improvements in the method of manufacture made it easy to attain far greater accuracy both of weight and fineness; consequently the remedy permitted by law has been considerably reduced, and the possibility of making a large amount of profit by this means proportionally diminished.[1]

The seigniorage levied on the coining of money was not a fixed rate, but varied considerably at different times, and accrued from a deduction made from the bullion coined. It was abolished by an Act of Charles II., which provided that whoever brought sterling silver or standard gold to the mint should receive in exchange an equal weight of current coin, the expenses of coining being defrayed by means of duties levied upon certain commodities of common use. The seigniorage on silver was revived in the reign of George III., when that part of the Act of Charles II. which related to the coining of silver without charge was repealed, and another Act was passed, requiring every pound of silver to be coined into sixty six shillings instead of sixty two,—the four shillings realized on each pound of silver by this depreciation of its value being handed over to the master of the mint to defray the expenses of assaying, loss, and manufacture. An Act of William IV. required the seigniorage on the silver coinage to be paid to the credit of the Consolidated Fund, and the charges of the mint to be brought annually before parliament. Against the profit derived by the state from this source must be placed the expense of maintaining the silver coinage in a condition fit for circulation by frequently withdrawing, recoining, and reissuing the silver coins. A vote of £15,000 is annually taken in the mint estimates for the loss on the recoinage of silver.

In former times the work of the mint was performed by contract, the mint master undertaking the manufacture of the coinage at a stated price, and paying the moneyers and other officers and workmen under him at a fixed tariff. The agreement made between the crown and the mint master, called the "master's indenture," was sometimes purposely kept secret. This system appears to have prevailed from the reign of Edward I., when an agreement was entered into between the king and the first master of the mint (appointed about 1279). Under this agreement an allowance was secured to the master to cover all the expenses of coinage. Although the master of the mint ceased to be a contractor, the arrangement with the managers continued in force up to 1851.

The work of coinage was transferred in 1810 from the Tower of London, where it had been carried on for many centuries, to the present Mint on Tower Hill, not far from the Bank of England. The head of the department, as has already been stated, is the chancellor of the exchequer for the time being, who is *ex officio* master of the mint,—the practical direction of the work being placed in the hands of a permanent officer, the deputy master, who is responsible for its due performance. From the English mint is supplied the coinage for the whole of the British empire, including the colonies, with the exception of Australia, the latter and the East Indies are supplied from branch mints established at Sydney and Melbourne, and the mints of Calcutta and Bombay. In addition to the gold, silver, and bronze coins current in the United Kingdom, the English mint strikes gold coins of the value of two dollars for Newfoundland, silver coins of the value of fifty, twenty five, twenty, ten, and five cents respectively for Newfoundland and Canada, bronze pence and halfpence of special design for Jersey, and nickel pence, halfpence, and farthings for the West Indies. The number of coins of each separate denomination issued varies considerably in different years, the demand for special denominations of coin naturally determining the supply.

The following table (from official sources) shows the value of the gold and silver coins issued during the ten years 1871-81. The total value of the bronze coin issued in the same period is £112,890.

Date	Gold Coinage[2]			Silver Coinage	
	Sovereigns	Half Sovereigns	Total Value	Half Crowns	Florins
	£	£	£	£	£
1872	13 643 885	1 617 556	15 261 441		692 010
1873	2 382 835	1 001 733	3 384 568		596 574
1874	519 629	941 936	1 461 565	273 240	180 774
1875		243 264	243 264	138 996	114 246
1876	3 294 705	1 401 943	4 696 648	79 200	60 786
1877		981 468	981 468	55 836	68 706
1878	1 106 289	1 158 780	2 265 069	183 150	178 596
1879	17 525	17 525	35 050	112 662	135 432
1880	3 645 853	504 199	4 150 052	168 102	232 274
1881				280 170	256 806
	24 610 721	7 868 408	32 479 129	1 291 356	2 516 194

Date	Silver Coinage[3]									
	Shillings	Six pences	Four pences		Three pences		Two pences		Pence	Totals
	£	£	£	s	£	s	£	s	£	£
1872	443 322	94 446	69	6	13 916	2	39	12	33	1 243 836
1873	324 324	109 890	69	6	50 744	2	39	12	33	1 081 674
1874	275 022	105 732	69	6	55 694	2	39	12	33	890 604
1875	217 800	81 378	69	6	41,438	2	39	12	33	594 000
1876	38 412	20,988	69	6	22 826	2	39	12	33	222 354
1877	163 350	101 772	69	6	31 142	2	39	12	33	420 948
1878	156 222	65 538	69	6	30 350	2	39	12	33	613 998
1879	180 576	83 160	69	6	37 082	2	39	12	33	549 054
1880	242 154	96 426	69	6	22 430	2	39	12	33	761 508
1881	262 548	156 816	69	6	40 646	2	39	12	33	997 128
	2 303 730	916 146	693	0	346 269	0	396	0	330	7 375 104

The British sovereign or twenty shilling piece was first issued by proclamation dated 1st July 1817, superseding the guinea or twenty one shilling piece. Crown pieces of the nominal value of five shillings were first struck in the reign of Henry VIII., six pences and threepenny pieces are first mentioned in the reign of Edward VI., while the groat or fourpenny piece was coined as early as the reign of Edward I., the florin or two shilling piece was introduced in 1849. Copper money was first coined by Charles I. in 1665, but does not appear to have been issued until 1672. Copper was replaced by bronze in 1860.

The weight and fineness of the various denominations of coin struck at the Royal Mint is shown in the first schedule of the Coinage Act (33 Vict. c. 10), 1870:—

---

[1] Two notable instances are recorded of the use that has been made at various times of the shere, or remedy, as a means of profit, one being in the reign of Queen Elizabeth, when Lonison, then master of the mint, finding the allowance made him under his contract was insufficient to cover the expenses of coining availed himself of the remedy on the silver coinage, amounting to 6½d. in the pound troy. The other occurred at the time of the great recoinage of silver in the reign of William III., when the profit of the shere amounted to 3d. per pound weight, or rather more than 8s. in every hundred pounds of money.

[2] In these gold returns fractions of pounds sterling are omitted.

[3] The numbers and weights of the fourpences, twopences, and pence, being Maundy coins, are the same for each of the years,—4518 fourpences, 4752 twopences, and 7920 pence.

Denomination of Coin	Standard Weight		Least Current Weight		Standard Fineness	Remedy Allowance		
	Imperial Weight Grains	Metric Weight Grammes	Imperial Weight Grains	Metric Weight Grammes		Weight per Piece: Imperial Grains	Weight per Piece: Metric Grammes	Millesimal Fineness.
Gold—								
Five pound	616 37239	39 94028	612 50000	39 68935	$\frac{11}{12}$ fine gold $\frac{1}{12}$ alloy or millesimal fineness 916 66	1 00000	0 06479	0 002
Two pound	246 54895	15 97611	24 00000	15 87 74		0 40000	0 02592	
Sovereign	12 2 447	9880	122 50000	7 93787		0 20000	0 01296	
Half sovereign	61 637 3	3 99402	61 12500	3 96083		0 10000	0 00648	
Silver—								
Crown	436 36363	28 27590			$\frac{37}{40}$ fine silver $\frac{3}{40}$ alloy or millesimal fineness 925	1 81818	0 11781	0 004
Half crown	218 18181	14 13795				0 90909	0 05890	
Florin	1 4 54545	11 31036				0 7 7	0 04712	
Shilling	8 272 2	5 6 18				0 36363	0 02356	
Sixpence	43 63636	2 82 59				0 18181	0 01178	
Groat or fourpence	29 09090	1 88 06				0 12121	0 00 8	
Threepence	21 81818	1 413 9				0 0 0	0 00589	
Twopence	14 5454	0 94253				0 06060	0 00392	
Penny	7 27272	0 47126				0 03030	0 00196	
Bronze—								
Penny	145 83333	9 44984			Mixed metal — copper tin and zinc	2 91666	0 18899	None
Halfpenny	8 0000	66 90				1 75000	0 11339	
Farthing	43 750 0	2 8349				0 8 500	0 05669	

The weight and fineness of the coins specified in this schedule are according to what is provided by the Act 56 Geo III c 68 that the gold coin of the United Kingdom of Great Britain and Ireland should hold such weight and fineness as were prescribed in the then existing mint indenture that is to say that there should be nine hundred and thirty four sovereigns and one ten shilling piece contained in 20 ℔ weight troy of standard gold of the fineness at the trial of the same of 22 carats fine gold and 2 carats of alloy in the pound weight troy and further as regards silver coin that there should be sixty six shillings in every pound troy of standard silver of the fineness of 11 ounces 2 pennyweights of fine silver and 18 pennyweights of alloy in every pound weight troy

The present standard of fineness for gold 22 parts fine or pure gold and 2 parts of alloyed metal was finally adopted in the reign of Charles II and has remained unchanged up to the present ime Before the passing of the Act determining this standard considerable changes had been made from time to time the highest degree of fineness having been reached in the reign of Henry III when the first gold coins were struck of the standard of 24 carats pure gold The standard of fineness for gold at some different periods may be seen from the following table which shows the composition of some of the ancient gold trial plates of which portions are preserved in the Mint —

Date	Standard prescribed by Law		Standard found by Assay	Remedy or Permitted Variation in Carats and in Thousandths	
	In Carats and Grains	Decimal Equivalent			
1349				$\frac{1}{3}$ carat or	13 9
1477	23 3½	994 8	Gold 993 5	$\frac{1}{8}$	5 2
1542	22 0	916	91 5	$\frac{1}{6}$	6 9
1543 (?)	23 0	9 8 4	9 4 4	$\frac{1}{6}$	6 9
1553	23 3½	994 8	9 3	$\frac{1}{6}$	6 9
1560	22 0	916 6	13	$\frac{1}{6}$	6 9
1560	23 3½	994 8	9 4 3	$\frac{1}{8}$	5
1593	22 0	916 6	91 9	$\frac{1}{6}$	6 9
160	23 3½	994 8	99 3	$\frac{1}{8}$	5 2
1649	0	916 6	913	$\frac{1}{6}$	6 9
1660	23 3½	994 8	993 9	$\frac{1}{6}$	6 9
1660	22 0	916 6	91	$\frac{1}{6}$	6 9
1688	22 0	916 6	914 6	$\frac{1}{6}$	6 9
1707	22 0	916 6	1 1	$\frac{1}{6}$	6 9
17 8	22 0	916 6	916 1	$\frac{1}{6}$	6 9
1829	22 0	916 6	915	$\frac{1}{16}$	2 6
1873	22 0	916 6	91 1		9 0
1873	Supplementary plate		Fine gold		

The earliest trial plate of which there is any record was made in the seventeenth year of Edward IV Before that time it would seem that the coins were compared with others known to be of standard fineness since among the Cotton MSS is preserved the account of the trial of the pyx of gold nobles in 1349 when the coins were compared with an ounce of florins of Florence kept in the Treasury as standards The first gold coins were 24 carats fine or pure gold Edward III caused coins to be struck of 23 carats 3½ grains fine in 1345 but no trial plate of this standard was made until 1477 Henry VIII lowered the standard to 22 carats but caused coin to be struck both of that and the former standards The greatest debasement of the standard ever reached in England was in 1546 when it sunk as low as 20 carats It reached a low point in the early part of Edward VI s reign but was raised towards the end of it to 22 carats and it was still further raised to 23 carats 3½ grains by Elizabeth, who however caused gold coins of 22 carats also to be struck Charles II on his accession rejected the trial plates of the standard of 22 carats which had been made under the Commonwealth and caused others to be made of the standard of 23 carats 3½ grains No coins, however appear to have been struck of this standard The same monarch afterwards fixed the standard at 22 carats and no variation in the legal standard has occurred since that time The last new trial plates made in 1873 were alloyed with copper only, in order that they might correspond with the composition of the British gold coins former plates having been alloyed with silver and copper At the same time supplementary plates of pure gold and silver were prepared in order that the greatest possible accuracy might be secured

The present standard of fineness of silver for coinage was fixed at a very early period but has been subject to considerable variation since the reign of Edward I the first English monarch who debased the silver coinage In the reign of Henry VIII it was once reduced as low as 4 ounces of silver to 8 of alloying metal, and Edward VI reduced it even lower It was restored by Elizabeth to the original standard

The following table shows the composition of some of the ancient silver trial plates of which portions have been preserved in the Mint —

Date	Standard prescribed by Law		Standard found by Assay	Remedy or Permitted Variation in Dwts and in Thousandths
	In ozs and dwts	Decimal Equivalent		
No date			Silver 4	
14 7	11 2	9 5 0	9 3 5	2 dwts
159 (?)			885 5	
154	9 6	5 0	63 6	3 dwts ( ) or 1
1 53	11	925 0	9 7 0	2 dwts or 8 4
1560	11	5 0	930	2 8 4
1600	3 0	250 0	2 2 0	3 1 5
1601	11 2	925 0	925 1	2 8 4
1604	11 2	925 0	9	2 dwts
1649	11 2	9 5 0	923	2
1660	11 2	925 0	924 2	2 dwts or 8 4
1688	11 2	9 5 0	0	2 8 4
170	11	925 0	9 0	2 8 4
1 28	11	92 0	9 6 9	2 dwts
1829	11 2	9 0	925 0	1 dwt or 4 2
1873	11 2	5 0	924 96	4 0
18 3	Supplementary plate		Pure silver	

The alloy used for the bronze coinage is composed of 95 per cent of copper 4 of tin and 1 of zinc The bronze coinage superseded the old copper coinage in 1860 the latter having been in use since the reign of Charles II The vicissitudes of the copper coinage were even greater than those of the superior coinage coins for Ireland having been issued at one time of pewter and of other alloys in which scarcely any copper was contained

The annual testing of the standard of gold and silver coins, called the trial of the pyx, from the "pyx" or chest in which the coins to be examined are kept, is a ceremony of very ancient institution It arose from the circumstance that the mint master was originally a contractor, under the crown, for the manufacture of the coinage, and it was therefore necessary that periodical examinations of the coins should be held in order to ascertain that the terms of his contract had been complied with At the present day, when the mint master is no longer a contractor, but an officer of the crown, the trial of the pyx has a somewhat different object, but it would appear from the description of these periodical examinations in some of the earliest mint records that but little change has taken place in the manner of conducting them The finished coins are delivered to the mint master in weights called "journey weights," supposed to be the weight of coin which could be manufactured in a day when the operations of coining were performed by the hand The journey weight of gold is 15 ℔ troy, coined into 701 sovereigns or 1402 half sovereigns The journey weight of silver is 60 ℔ troy From each journey weight a coin is taken and deposited in the ' pyx or chest for the annual trial This is made by the freemen of the goldsmiths' company under the direction of the crown in the presence of the queen s remembrancer, who administers the oath to the jury and presides over the proceedings The coins selected for trial are compared with pieces cut from trial plates of standard fineness, which are in the keeping of the warden of the standards, these pieces being assayed against the coins under examination If the coins are found to be of the standard fineness and weight within certain limits, a verdict to that effect is drawn up by the jurors and presented to the Treasury

In consequence of the impossibility of ensuring an absolutely exact admixture of metals in coining it has been found necessary at all times to allow to the mint master a certain margin or "remedy within which coins may vary in weight and fineness from the fixed standard and still be considered of the current standard The remedy of fineness for English gold coin is now fixed at 2 parts per 1000 The great importance of maintaining the standard of fineness for gold will be evident when it is stated that the variation of $\frac{1}{10}$ of a millieme (or thousandth part) above or below the standard causes a gain or loss of £100 in every million sterling Gold coins would be within the remedy of fineness permitted by law if the amount of precious metal contained in them varied from 914 6 to 918 6 parts in 1000, and, although this remedy cannot be considered to be more than would meet occasional and unavoidable deviation from the exact standard, still, in the case of gold but a very small part of the remedy of fineness is actually used, the coins seldom falling below 916 3 parts of gold in 1000, or rising above 917 0, while the mean composition of many millions of coins issued from the mint is often of the precise legal standard, 916 66 The remedy of fineness for silver coin which appears to have been always greater than that for gold coin is 4 parts per 1000 The remedy of weight for gold is 1 6 per 1000 parts, that for silver 4 17, and that for bronze 20 Extreme care is taken to prevent the issue from the mint of any coins that exceed these permitted variations in weight and standard each coin being weighed separately, and all those found to be above or below the standard being returned to the melting house

Since the real value of the gold coinage is the same as its nominal value it is of the first importance that gold coins which are below the standard weight should not be allowed to circulate, otherwise holders of large quantities of gold coin are liable to considerable loss After a certain amount of wear a gold coin in passing from hand to hand loses weight and becomes legally uncurrent By the Coinage Act it is made compulsory for every person to cut break or deface any coin tendered to him in payment which is below the current weight, the person tendering it bearing the loss but as no penalty is imposed for disregard of this obligation, the law is practically without effect The withdrawal of light coin from circulation was formerly accomplished solely by the Bank of England the mint regulations making provision for the receipt of gold tendered for coinage only in the form of bars The bank undertook to purchase the light gold from the public at the rate of £3, 17s 6½d an ounce, a price which as compared with the mint value of £3, 17s 10½d entailed a loss of no less than 4d an ounce on the seller This loss was occasioned chiefly by the circumstance that the bank, being obliged before sending the light gold to the mint for recoinage to melt, assay, and cast it into bars, found it necessary to deduct the sum of 2½d an ounce from the rate of £3, 17s. 9d an ounce at which it was allowed by statute to purchase gold for coinage, in order to cover the expense of these operations and the loss incident to them The heavy loss in price, added to that from deficient weight, occasioned constant disregard of the law requiring all light coin to be cut or defaced, and consequently a large amount of light gold continued to be circulated After the passing of the Coinage Act in 1870, accordingly, fresh regulations were made, by which the mint authorities undertook to receive light gold coin for recoinage, returning to the importer the full mint value of £3, 17s 10½d an ounce, thus reducing the loss to that arising from deficiency of weight only As the Bank of England was enabled by these regulations to raise its price for light gold to the rate of £3, 17s 9d, the same rate at which it is bound to purchase ingots of standard gold, greater inducements were offered to the public to send in light gold for recoinage, and its withdrawal from circulation was in consequence greatly facilitated It is evident, however, that, as the deficiency in weight must entail some loss on the holders of light gold coin, they will be disposed to keep it in circulation as long as possible, consequently only a small proportion of the light gold received by bankers finds its way to the Bank of England and thence to the mint for recoinage The result of some careful experiments made by the late Mr Stanley Jevons, and published by him in the *Journal of the Statistical Society* (vol xxxi p 426), showed that a sovereign becomes so light as to be legally uncurrent at the end of eighteen years The last state measure taken for the withdrawal of light gold coin from circulation was the issue of a royal proclamation in 1842 calling attention to the laws and regulations relating to light gold coin, and instructing those persons whose duty it was to enforce them to see that they were carried out From the beginning of July 1842 to the end of March 1845 £14 000 000 in light gold coin was withdrawn from circulation and recoined This amount was estimated to represent 95 per cent of the whole of the light gold then in circulation In order to facilitate this withdrawal the Treasury had in June 1842 entered into arrangements with the Bank of England by which the bank was enabled to purchase light gold on behalf of the Government at the full mint value of £3, 17s 10½d an ounce Light coin, however, continued to be sent into the bank for some time after it had reverted to its original rate of payment for light gold *i e*, £3 17s 6½d an ounce The expense to the state of this withdrawal, including the expenses of recoinage was £67,816 As no important withdrawal of worn gold coin has occurred since that time, it is evident that a large amount of light gold must be at the present time in circulation and that the loss in weight must be considerably greater than that of the coins withdrawn in 1842, the oldest of which were not more than twenty five years old the first issue having taken place in 1817 It has been proved by experiment that the average loss of weight in worn sovereigns and half sovereigns now in circulation is about 3d in each sovereign and that the deficiency in fineness of a large proportion of the coin amounts to about £400 per million This deficiency arises from the trial plate of 1829, which determined the standard of a portion of the coins still in circulation, being itself below the legal standard Taking the gold circulation at £100,000,000, of which about 50 per cent is light, it is estimated that the amount to be recoined cannot be less than £50,000,000, on which the loss from deficiency of gold, both in weight and fineness, must be reckoned at about £650,000, independent of the expenses of recoinage

In the case of the silver coinage, the loss consequent on the withdrawal and recoinage of silver money is now covered by the seigniorage arising from the difference between the real and the nominal value of the coins Before the adoption of gold as the sole standard of value, the conditions attending the withdrawal and recoinage of silver were much the same as those for gold In the period between the reign of Charles II and the accession of William III the condition of the silver coinage became so unsatisfactory as to demand the attention of parliament A recommendation made at the suggestion of Sir Isaac Newton for a recoinage of silver was at first strenuously opposed, but was finally adopted In the course of the discussion the question of raising the standard of weight and fineness arose, and this important change would probably have been made but for the representations of Locke, who warmly took up the question and convinced the Government of the desirability of preserving the established standard In the great recoinage of silver, the loss arising from clipped and defaced coin was borne by the public, the money being raised by means of a special tax on glass windows The silver reissued at this time amounted to £7,000,000, and the tax raised to cover loss and the expenses of coinage to £1,200,000 The work of this recoinage was so great that the resources of the mint in London were found to be unequal to the pressure put upon them, and therefore mints were either revived or established for the first time in a few of the large provincial towns In addition to this ten furnaces were erected behind the Treasury at Whitehall to melt down the old pieces By these means the renovation of the silver coinage was completed within the year The new silver coins then issued were the first which had milled edges, the milling having been introduced in order to prevent clipping

The mode in which the silver currency is distributed throughout the kingdom is explained by the late Mr George Forbes, cashier of the Bank of England as follows —

Every banker in the kingdom has a banker who is his agent in London Every London banker has an account with the Bank of England In the Bank of England there is a department devoted to the issue and receipt of silver coin If in a district there is a deficiency of silver currency the bankers of the district are the first to find it out They at once write to their London agents who draw on their account with the Bank of England, and obtain what silver is required which they send to the country banker On the other hand, if there is a surplus of silver in a district it accumulates in the coffers of the local bankers who send it up to their London agents and they send it into the Bank of England If there is a general demand for silver currency, the stock which the Bank of England endeavours to keep on hand becomes unduly diminished and immediate notice of the fact is conveyed to the mint authorities who proceed with all convenient speed to coin a supply of florins shillings, sixpences, or of all of these coins as the nature of the demand may require

Gold bullion for coinage is supplied to the mint almost entirely by the Bank of England, the bank being bound by law to purchase at the rate of £3, 17s 9d an ounce any gold bullion of the legal standard which the public may bring for sale Private individuals are permitted to bring bullion to the mint, and to receive back the full amount (at £3, 17s 10½d an ounce) converted into coin, free of any charge for loss or manufacture but, as they are subject to considerable delay, all "importations' of bullion being converted into coin in the order in which they are brought to the mint, the public practically prefer to sell their bullion to the bank, and receive its value without delay In order to be accepted by the bank, the bullion must be cast into ingots and assayed, a guarantee being given by certain recognized assayers that the gold is of a certain standard fineness This is known as the "trade assay" When the bank requires gold to be struck, due notice is sent to the deputy master, and on a fixed day the bullion is conveyed to the mint and delivered into his custody It arrives in the form of ingots, each weighing about 200 ounces, the aggregate value of each importation being about £144,000 When the ingots arrive at the mint a small sample is taken from each and assayed,[1] the result being sent to the authorities of the bank in order that it may be compared with that of the trade assay If the bank authorities find that the two assays agree, within certain limits, as to weight and fineness, the ingots are immediately sent to the operative department of the mint to be converted into coin The mint assay affords the basis for calculating the amount of copper, the alloying metal, that must be melted with the gold in order to produce the standard prescribed by law The case of silver is somewhat different, the bullion being purchased by the department at its market value, which varies from year to year During the ten years ending 1881 the average price of silver bullion sank gradually from 60$\frac{5}{16}$d to 51$\frac{13}{16}$d The silver bullion arrives at the mint in the form of ingots, each of which weighs about 1000 ounces, the value of each set of ingots varying considerably The ingots, both of gold and silver, are weighed on a balance capable of turning with 1 grain when loaded with 1200 ounces

The operations of coining have undergone some slight changes with the introduction of new machinery and the increased extent of the Royal Mint, since the reconstruction of the operative department in 1881[2] The plan (fig 1) shows the present arrangement of the operative department

The operations employed in the manufacture of gold and silver coin are as follows (incidental operations being printed in smaller type) —

I Assaying the bullion

II Melting the metal

(*a*) Addition of the amount of copper necessary to form the prescribed alloy *b*) pouring the metal into moulds so as to form bars (*c*) dressing these bars to remove rough edges and hollow ends (*d*) recovery of precious metals from crucibles and ' sweep

III Assaying portions of metal cut from certain bars, to ascertain whether sufficient accuracy has been attained in the standard fineness

IV Rolling the bars into strips or "fillets."

Annealing the fillets in some cases)

V Adjusting the fillets by a final rolling, and in some cases by the use of the drawbench

Testing the fillets to ascertain whether they are of sufficient accuracy as regards thickness

VI Cutting out disks or blanks from the fillets

Adjusting the blanks in weight (in some mints)

VII Edge rolling the blanks to produce a raised rim.

Annealing the blanks and (in some cases) "blanching" or 'pickling" them in dilute acid

VIII Coining, or stamping the device on the blanks, by means of engraved steel dies

Milling the edges of the blanks or (in some cases) impressing a device inscription or ornament upon them

IX Weighing each coin, usually by the aid of automatic machinery

X Assaying and weighing pieces taken from the finished coin before it is issued to the public

The foregoing list will make it clear that the operations of minting consist, not simply in the mechanical production of accurately adjusted disks of metal the purity alone of which has to be guaranteed, but in the formation of an alloy composed of precious and base metals in definite proportions The accuracy of the "standard fineness of the alloy after melting must be absolutely ascertained, the alloy must be protected during manufacture against a change of standard, and finally its correctness must be verified after it has been converted into coin

---

[1] The assays are conducted in the manner already described in the articles ASSAYING and GOLD

[2] In order to provide a stock of silver coin during the temporary suspension of the work of the mint, a large coinage of silver was issued, and 50 tons of bronze coins were manufactured by contract in the autumn of 1881 The governor of the Bank of England had previously reported that the stock of gold coin held by the bank was abnormally large, and that no inconvenience would arise ' if the mint were to cease coining sovereigns and half sovereigns for a period of six months or a year or even more

The precious metals are weighed on entering the mint, as well as during various stages in the manufacture of coin The finished coins are also weighed in bulk before they are issued to the public

The operations incidental to the coinage of bronze and silver differ from those described in relation to gold in some unimportant details only and the weight and composition of the bronze coins are not so carefully guarded as is the case with gold and silver

Subjoined are the details of the operations involved in the conversion of bullion into coin at the British mint

After being assayed and weighed in the manner already described the bullion is taken to the melting house where the details of treatment for silver and gold respectively differ somewhat (The subsequent operations are nearly identical for both metals) The silver melting house (see fig 1) contains eight furnaces of the kind shown at A fig 2 the part of the furnace containing the crucibles being below the lids B B Crucibles of cast iron were formerly employed but these were replaced in 1853 by wrought iron pots which have since 1870 been in turn abandoned in favour of crucibles made of a mixture of clay and graphite each crucible being capable of containing about 3000 oz Such crucibles are very generally adopted throughout the Indian and Continental mints but the form and dimensions given to them vary The fuel employed in England is coke about 75 ℔ of which are required to melt 3000 oz of standard silver Sufficient draught is afforded by the flue C and by a chimney about 35 feet high which communicates with it The silver and copper are melted together, and before the metal is poured into moulds it is stirred with an iron rod having a flattened end The surface of the molten metal is covered with a layer of charcoal to prevent oxidation of the copper The crucible with its contents is then removed from the furnace by the aid of a crane and tongs W and is placed in a cradle M which can be tilted by means of a handle D By the intervention of toothed wheels F F G H and K acting on a rack the handle turns the crucible on the fulcrum formed by a spindle so that the contents of the crucible may be poured into the moulds N mounted on a carriage OP running on rails Q Q The moulds now in use in London are of such dimensions as to enable bars to be cast 12 inches long and ⅝ inch thick The width of the bars varies, according to the coin to be produced from 1⅜ to 2⅝ inches

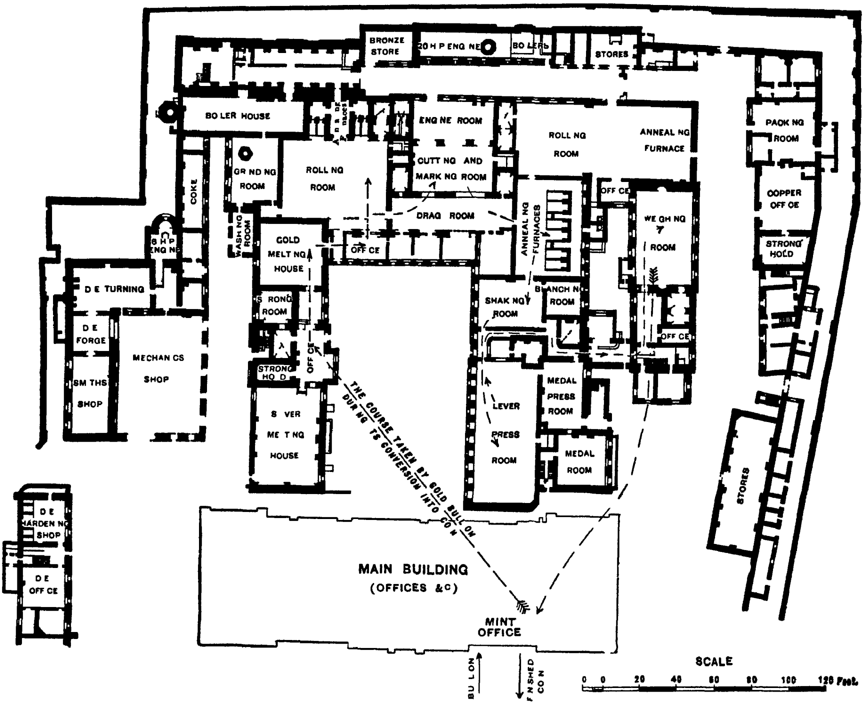


FIG 1 —Royal Mint, Tower Hill London Plan showing the Operative Department as rearranged in 1881 82

When the metal has solidified in the moulds it is removed and the bars are trimmed by the aid of a revolving circular file their ends being cut off and returned to the melting pot Portions of metal are then cut from certain of the bars and sent to the assay department The bars are weighed before they pass to the subsequent operations of coinage in order that the amount of metal retained by the crucibles or carried into the flues may be ascertained Gold bullion is melted in a similar way, but the crucibles are smaller and contain only 1200 oz Their contents are poured by hand into moulds one end of the tongs by which the crucible is grasped being supported by a chain and suspended from the roof [1] In many Continental mints it is very generally the practice to leave the crucible containing the precious metals in the furnace, and to pour the contents into the moulds by the aid of small ladles of wrought iron lined with clay

It has been pointed out in GOLD (vol x p 751) that minute quantities of certain metals render standard gold extremely brittle and unfit for coinage If either the gold bullion or the copper used as an alloying metal should be impure brittle bars will be the result Should this prove to be the case the bars are re-melted and chlorine gas is passed through the molten mass in the manner described in **Gold**, vol x p 750

---

[1] A new form of furnace devised by M A Piat of Paris has recently been introduced In these furnaces the portion which contains the crucible may be detached from the flue so as to admit of the molten metal being poured into moulds without removing the crucible from the incandescent fuel Four of such furnaces have been fitted up in the gold melting house but have not as yet been used for gold melting in the melting of silver and bronze, however, they are known to effect considerable economy in labour, fuel, and crucibles.

The engine room (shown in fig 1) contains three 60 horse power vertical condensing engines, which are provided with Corliss valves, and are specially devised for meeting the constantly varying *strain to which they are subjected by the machinery*, the whole of which they are capable of driving The central engine acts directly on either or both of the rolling rooms placed on each side of the engine house There is, however, an additional 20 horse power compound beam engine usually employed, in connexion with the pumps of a deep artesian well

Into one or other of these rooms the bars which have been cast in the melting house are brought, and are rolled into strips the thickness of which depends on the kind of coins to be produced. Gold is rolled in one room and silver or bronze in the other The details of manipulation involved in the conversion of gold, silver, or bronze bars into coin, however, do not differ materially, and the coinage of sovereigns will therefore be taken as typical

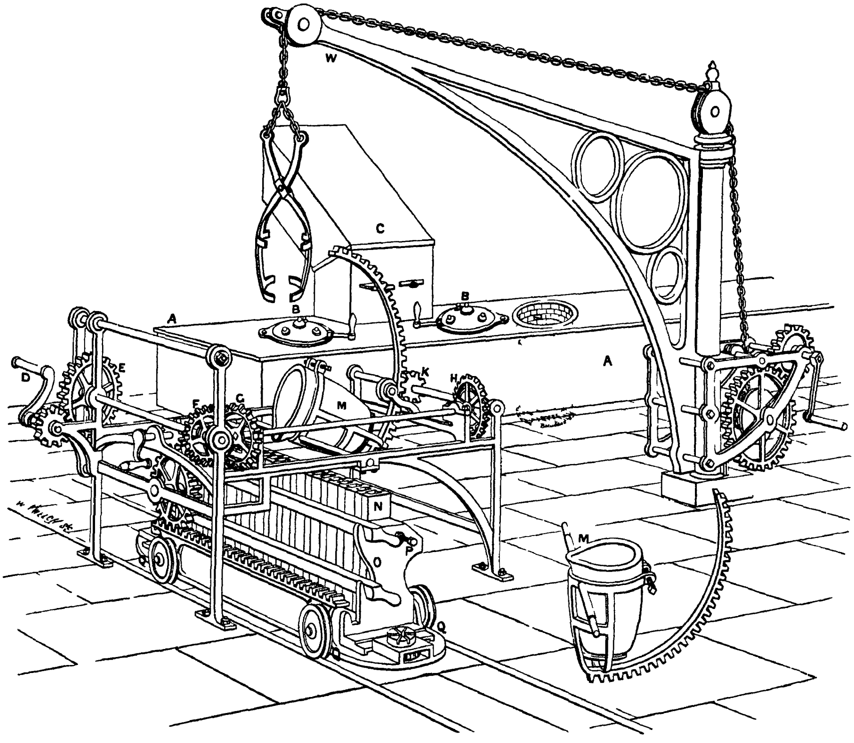


Fig 2 —Furnace Apparatus

Each room contains six pairs of rolls, the diameter of the rolls varying from 10 to 14 inches Smaller diameters are employed in most European mints but on the other hand the use of very narrow rolls of far larger diameter has often been suggested and there appears to be good ground for the belief that the rigidity of such rolls would enable strips or fillets of more uniform thickness to be produced than is the case at present The iron frame CC (fig 3) is firmly bolted to the stone D, which rests on a solid foundation EE This frame supports the two rolls A, B, the lower of which B revolves, but is not, like the upper, capable of adjustment in a vertical plane The upper roll is centred in bearings, and may be raised or lowered by means of screws connected with toothed wheels F, F which are turned by a handle G, both wheels being moved simultaneously by *worms on* the rod H The bearings of the upper roll are connected by vertical rods with weights below the level of the floor, and, as it rises with the screws, it can thus be readily adjusted in a line exactly parallel with the lower roll, at a sufficient distance from it to admit the bar which is to be reduced to a strip or fillet The rolls are turned by the shaft NN, the main wheel M, and the gearing K, L O, P The sockets *r* by which the upper roll is connected with the gearing by the shaft I are not rigid, as is the case with the shaft Q of the lower roll but admit of the adjustment of the roll The portion of the roll used is determined by a guide a little wider than the bar[1] The rolls throughout this department are driven at the rate of about 32 revolutions in a minute The iron frame CC is braced by rods *a*, *s*, and blocks bearing the driving shafts are shown at *k*, *k* *p*, *p*

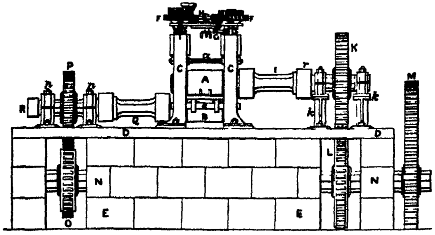


Fig 3 —Rolls

The initial thickness of a sovereign bar is $\frac{3}{8}$ths of an inch The bars are weighed out to the workmen in batches of about sixty bars an entire batch being passed through the rolls under precisely the same conditions of adjustment The bars are only slightly reduced in width by repeated passages through the rolls, but are successively reduced in thickness in the first stages of the rolling by $\frac{1}{15}$th of an inch, while in the later stages the reduction in thickness at each passage through the rolls is less than $\frac{1}{100}$th of an inch, and finally one or two "spring pinches" are given to the bars by simply passing them through the rolls without altering the adjustment. The testing of the fillets to ascertain whether they are of the accurate thickness, is effected by the aid of the gauge plate (fig. 4), which consists of two steel bars set at a low angle in relation to each other and graduated to $\frac{1}{1000}$th of an inch. It will be evident that the weight of the finished coin depends upon the thickness of the fillets, and to show how accurately the rolling must be performed it may be pointed out that, in the case of the half sovereign, a variation of $\frac{1}{20000}$th of an inch above or below the accurate thickness (or a range of $\frac{1}{10000}$th of an inch) throws the coin out of remedy.

---

[1] In the second rolling room shown in the plan on the right of the engine house the frames and gearing of the rolls are of newer pattern than those in the first room In some of the six pairs the bottom rolls revolve and drive the upper ones In the pair of "breaking down rolls in this room —that is, the roll by which the fillets are first treated,—the upper roll is stationary the lower roll alone revolving The necessary bite is given to the fillet when its end is introduced, by slightly turning the upper roll by means of a ratchet wheel and

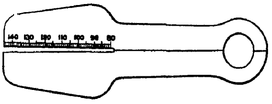


FIG. 4.—Gauge Plate.

The repeated passage through the rolls is attended by a considerable increase of hardness in the metal, and it is therefore in some cases necessary to anneal the fillets repeatedly during the rolling. In the case of fillets for sovereigns the annealing may be entirely dispensed with if the initial thickness of the bars does not exceed $\frac{3}{8}$ths of an inch. Fillets for half sovereigns have only to be annealed once. In some European mints the fillets are annealed frequently; in one mint the operation is performed after each passage through the rolls. The furnace used for the purpose is generally so arranged as to permit the flame to play over the fillets, which are sometimes freely exposed to its action, but are more often enclosed in cases or tubes. Muffle furnaces are frequently used. The furnace used in the Royal Mint is a simple form of reverberatory furnace. The final rolling is given by a pair of finishing rolls capable of more accurate adjustment than the "breaking down" rolls.

The fillets of gold or silver are in some cases, though not always, submitted to an appliance known as the drag bench, shown in figs. 5, 6, 7. Its object is to equalize the thickness of the fillets by drawing them between steel cylinders. The ends of the fillets are first flattened in a little appliance, which need not be described. The essential feature of the machine now used in the mint consists of two small steel cylinders A, A, which do not revolve and are held in position in the plates D, D by clamp pieces F, F screwed against them. The portions of metal may be adjusted by the aid of a wheel and screw H (figs. 6, 7), and by small adjusting screws *f*, *f*. The part of the machine containing the steel cylinders is fixed at the end of a long bench, and gearing at the other end of this bench drives an endless chain BB (fig. 6), one link or other of which catches the carriage shown in plan in fig. 5 and drags it along as soon as its end *f* is depressed by the handle *r*. The carriage runs on the wheels *d*, *d*. The drawing of the fillet C is conducted as follows. Its flattened end is introduced between the steel cylinders, and is grasped by the jaws *a*. The jaws turn on the pin *c*, and while the fillet is being dragged through the cylinders the axle of the wheels *d*, *d* tends to increase the grip of the jaws by acting on their inclined ends. Directly the strain on the fillet is released, the pins *i*, *i* and the weight *h* loosen the jaws and at the same time raise the end of the carriage so as to arrest its further progress along the bench. The carriage is then moved forward by the handle *s* until the jaws enter the hollowed portion N and grasp another fillet.

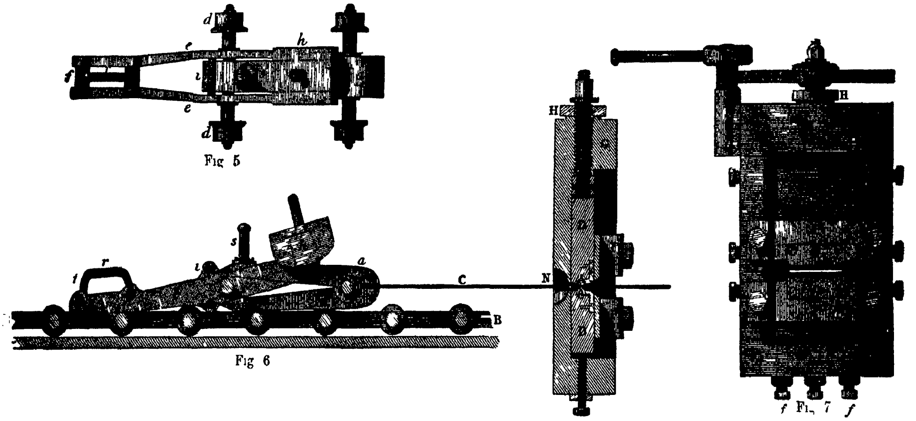


Fig. 5

Fig. 6

Fig. 7

FIGS. 5, 6, 7.—Drag Bench.

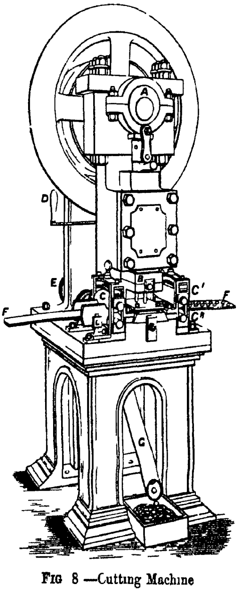


FIG. 8.—Cutting Machine.

Trying.

Formerly—when fillets were rolled from thick bars—this appliance played a more important part in coining operations than at present. It is now only used for fillets from which sovereigns and half sovereigns are to be produced. Before fillets are passed on to the next operation—that of cutting from them the disks or blanks destined to form the coin—they are carefully tested by a skilful workman called the "tryer," who cuts one or two blanks from the sides of each fillet by the aid of a cutter worked by hand. These blanks are weighed on a delicate balance against a standard weight, and the experience of the operator enables him to determine whether the variation from the exact weight will justify his sending the fillets forward to the cutting room. In any case he divides the fillets into two or more classes for a reason that will be explained presently.

Cutting blanks.

The cutters employed in the mint until quite recently were of complicated construction, but these have been replaced by a simple machine (fig. 8) which, by the revolution of an excentric A, causes two short steel cylinders, mounted on a block of iron B suitably guided, to enter two holes firmly fixed in a plate on the bed of the machine. When the fillet FF is interposed between the short cylinders and the holes, the former force disks of metal through the holes, the fillet being advanced at each stroke of the machine by small gripping rolls C, C′, C″ actuated by a ratchet-wheel E, driven from the shaft which bears the excentric A. The disks pass down the tube G to a receptacle placed on the floor. In the case of very large silver coins, only one disk is cut in the width of the fillet, and in some few mints disks for gold coin are also cut in this way, but it is far more usual to cut two disks in the width of the fillet, the position of the cutters being so arranged as to remove blanks in the manner shown in fig. 9. In cutting disks for bronze coin extreme precision is not necessary, and it has therefore been found possible to obtain five at each stroke of the machine.

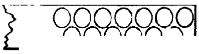


Fig. 9

It will be evident that the rough classification of the fillets according to their thickness, to which reference has already been made, renders it easy to compensate for slight irregularities in thickness caused by rolling, by employing cutters of a slightly larger diameter than the standard size for fillets which are too thin

The fillets after the removal of the disks present the perforated appearance shown in fig 9 The residual metal, called "scissel," which amounts to from 25 to 30 per cent of the metal operated upon, is returned to the melting house in bundles weighing 180 oz It may be mentioned here that all attempts to cut disks or blanks for coinage from the ends of rods or cylinders, and thus to avoid the production of scissel, have hitherto failed

The next operation to which the blanks are submitted varies in different mints In some, each blank is weighed by hand or by automatic machinery, and each blank that is too heavy is adjusted either to an exact weight or to within the remedy prescribed by law On the Continent it is very generally the practice to adjust blanks by the aid of a file, or by a machine that removes a fine shaving of metal from the surface of the blank In mints where mechanical adjustment is adopted there is a tendency to produce "too heavy blanks in the rolling and cutting departments, as it is impossible to adjust blanks which are too light[1]

In the London mint finished coin alone is weighed, so that the blanks after leaving the cutting room pass directly to an edge rolling machine, which thickens the edge of each blank so as to form a rim intended to protect the impression on the finished coin The operation of edge rolling is called "marking, and the method of conducting it varies considerably in different mints

In the Royal Mint the blanks are made to pass in quick succession, at the rate of six hundred a minute, between a circular groove in the face of a revolving steel disk and a groove in a fixed block placed parallel to the face of the revolving disk The groove in the block exactly corresponds to that on the disk, and, as the distance between the block and the disk is slightly less than the diameter of the blank submitted to the operation, the result is that before the blank escapes from the machine its edge has been thickened The operation may be varied by admitting the blanks between a groove in the periphery of a revolving wheel and a groove in a segmented block, placed at a distance from the wheel rather less than the diameter of the blank The wheel and block may be either vertical or horizontal

In some cases the edges of the blanks at the same time that they are thickened, receive the impression of a legend, or inscription, or an ornamental device When this is the case the blank is rolled between two planes one of which is fixed and bears the device, while the other has a reciprocating motion imparted to it, or the edge of the blank receives the impression which may be either raised or sunk, from a collar surrounding the blank in the coining press, as will be afterwards explained

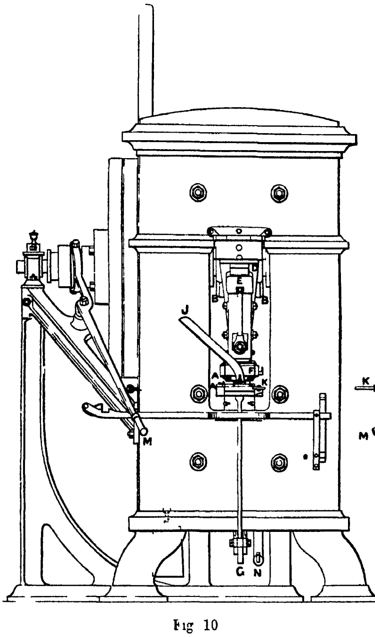


Fig 10

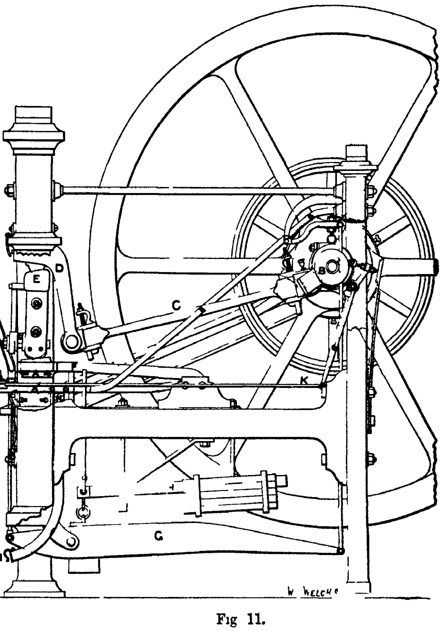


Fig 11.

Before passing to the coining press the blanks either of gold or silver are annealed In many mints the object of the heating is not only to soften the blanks before they receive the impression, but also to produce a film of oxide of copper on their surface This is attained in various ways In England gold blanks are placed in cylindrical crucibles of plumbago and covered with a layer of charcoal heated in a reverberatory furnace, and when the blanks reach cherry redness they are cooled by plunging them in water The thin film of oxide of copper thus formed on the surface of the gold or silver blanks is readily soluble in dilute sulphuric acid, and the removal of a small portion of the alloying metal in this way constitutes "blanching or "pickling the coin The method of conducting the operation varies somewhat in different mints, mainly, however in the strength of the acid used which varies from 3° to 5° of the hydrometer of Baume The solution is sometimes heated to 96° to 98° C , while in other cases the blanks are introduced into the solution while at a red heat The latter method is, however, objectionable as a dense layer of pure metal is found at the surface of the blank which is apt to protect the underlying oxide of copper from the action of the acid The blanks are afterwards washed in pure water and dried either in sawdust or in copper vessels heated by steam jackets. The object of the process is to improve the appearance of the finished coin by removing all traces of impurity from the surface of the blank. It has, however, been abandoned in the British mint except in the case of some of the smaller silver coins, mainly because the soft superficial layer of metal wears away with undue rapidity. Certain precautions suggested in 1869 by Mr Hill, the superintendent of the operative department, for avoiding oxidation or tarnishing of the metal during coinage rendered the abolition of the process possible.

---

[1] A description of a machine used for the adjustment of blanks will be found in *Dingler's Polytechnisches Journal* (1882 ccxlv [illegible]) and some years ago Mr J M Napier devised for the Indian mints a beautiful machine which first ascertains how much it is necessary to cut from each blank in order to reduce it to the standard weight, and then removes the necessary amount of metal and no more The initial cost of such machinery however is considerable In 1849 M Dierick director of the mint in Paris endeavoured to substitute a chemical for a mechanical treatment by submitting the heavy gold blanks to aqua regia which it was anticipated would bring them within the prescribed limits of accuracy The results were not satisfactory and the attempt was abandoned In 1870 the present chemist of the mint Professor W Chandler Roberts showed that gold alloyed with copper might be removed from heavy blanks with singular regularity by means of a suitable solvent aided by a battery The blanks are arranged in a frame of wood and submitted to the action of a solution of cyanide of potassium the heavy blanks forming the dissolving pole of the battery The process was not used in the London mint as it became evident that it could not profitably replace the present system under which fi
weighed and the manufacture of good coin only b
introduced into the Bombay mint in 1870 by the
extended its usefulness by transferring the metal dissolved from the heavy blanks to blanks which are too light the latter being by this means raised to the prescribed weight The process has now fairly taken its place as an ordinary operation of coining and its importance to the mints where it is used may be gathered from the fact that in the Indian mints no less than 1300 tons of silver were converted into coin in one year (187[illegible]) so that the saving effected by its introduction must be considerable

The blanks receive the impression which constitutes them coins from engraved dies. Each is placed in the lower of two dies and the upper die is brought forcibly down upon it. The lateral escape of the metal is prevented by a collar which surrounds the blank while it is being struck. This collar may be either plain or engraved, and if the latter is the case any device or ornament it may bear will be imparted to the edge of the blank.

The coining presses used in various mints may be divided into three types:—(1) the screw press worked by atmospheric pressure, (2) the excentric press, and (3) the lever press. The first of these (see *Ency. Brit.*, 8th ed., vol. vii. p. 92) has now been abandoned. In the excentric press the power is applied to a shaft bearing an excentric which acts by means of a connecting rod upon a vertical slide holding the die which is brought down on the blank. This form of press is used in the mint at Constantinople, where the atmospheric screw press is also still retained. Of the third type, the lever press, there are two modifications, devised respectively by Thonnelier and by Uhlhorn. The details of the Uhlhorn press have been improved by Messrs R. Heaton & Sons of Birmingham, and, their superiority to the old vacuum screw press having been demonstrated by careful experiments, they have been finally adopted in the newly arranged mint, which contains fourteen of them. This press is shown in figs. 10 and 11. It is driven from below the floor of the press room by bands which pass over fast and loose pulleys *on the same shaft that bears the fly wheel.* The loose pulley, however, is only used when it is necessary to stop the machine entirely, as the fly wheel is permitted to revolve without imparting motion to the shaft so long as a lever M worked from the front of the machine does not cause the fly wheel to be connected with the driving wheel by means of two pins. The dies are placed in the front part of the machine (fig. 10). The lower one is firmly fixed to the bed, while the upper is held at A by the upper of two jaws F and A, or levers, the fulcra of which are so close together as almost to coincide, the lower jaw A bearing the collar which encircles the blank while it is being converted into a coin. The upper jaw F A, governed by the weighted lever H shown below the bed of the machine, has a tendency to rise a sufficient distance to admit the blank between the upper and lower die. A crank B on the shaft bearing the fly wheel is connected by a rod C with the bent lever D, and this bent lever acting through the toggle joint and a piece of metal E connected with the jaw that bears the upper die forces it down, and thus squeezes the blank between the upper and lower dies. A cam on the crank shaft acting on the lower of the two levers G shown below the bed of the machine causes the lower jaw A bearing the collar which surrounded the blank to be depressed sufficiently to leave the finished coin freely resting on the lower die, from whence it is driven down the shoot N by the next blank in succession. Coins are produced at rates varying from 60 to 120 a minute, 90 a minute giving the best results. The blanks to be converted into coins are placed on the slide J and the advance of each blank in succession is regulated by the rod called the "layer on" K, the backward and forward movement of which is also regulated by an excentric on the crank shaft. The details of this part of the machine are shown in plan, fig. 12.

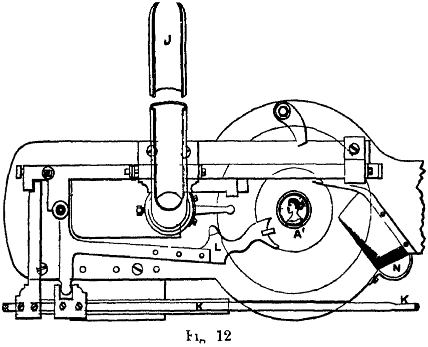


Fig. 12

The last operation before the finished coin is returned to the mint office for issue to the public is the weighing each gold or silver piece separately. This is effected in the American and in most Continental mints by hand, but in England automatic balances of beautiful construction are employed. They were originally devised for separating worn pieces from those of current weight, but they are now employed to distinguish between "light," "heavy," and "good" pieces, the latter alone being permitted to pass into circulation. In the newly arranged department thirty such machines are provided. Each is driven from overhead shafting by means of gut lines. The driving pulleys derive their motion from a small atmospheric engine, which is found to give more satisfactory results than would be the case if the steam engine were employed directly. Each balance is worked by a cone pulley A (fig. 13) by a gut line passing round it from the loose pulleys B, the necessary tension being imparted to the line by means of a spring C. The tension of the line is, however, but slight, for if the action of the balance is arrested by accident the cord slides over the cone pulley A without turning it. It will be obvious that the use of the cone pulley enables the machine to be driven with varying degrees of speed. The toothed wheel D is mounted on the spindle which bears the driving pulley A, but it acts only through the intervention of a friction check, which is so lightly screwed against the driving wheel that it would cease to act if the machine should be accidentally deranged. The wheel D sets in motion the wheels E, E, E. The cam F acting on the curved extremity of the rocking frame G, causes the slide H to bring forward one of a series of coins (arranged in the hopper I) until it rests on the plate J of the balance beam, of which beam a portion is shown in an enlarged drawing above the balance, while the plate that receives the coin is also shown in a separate drawing to the left of the machine. Another cam K then comes into play, and enables the forceps, shown at L, to release the rod M to which the balance plate J is attached. The forceps L serves to keep the rod steady while the coin is being placed on the plate J. A rod shown at N is then raised by the cam O, the lower extremity of the rod being kept steady by a pin sliding in a hole in the bottom plate of the balance and its upper end by a pin which works into the central support of the balance beam. At the base of this rod N and at right angles to it there is a metallic bar QQ, the ends of which pass through stirrups in the pendants M and P from the opposite ends of the beam. The elevation of this horizontal rod by the cam O simultaneously releases both ends of the beam, and the coin placed on the beam plate has then, for the first time, a direct influence on the beam. If the coin is "too light," the counterpoise R in the cage at the end of the rod P will raise the coin, and the revolution of the machine then causes part of the cam K to permit a spring to close the forceps L and to hold the pendant M firm. An indicating finger T then falls and by means of a horizontal lever UU, which fits into one of three inverted steps on the bottom of the shoot V, determines over which of three orifices W, W, W in the bottom plate of the balance this shoot shall stand. In the meantime the advance of the slide H brings the next piece forward, and displaces the coin which has hitherto occupied the beam plate J, forcing the coin down the shoot V and thence through the orifice W into a receptacle external to the balance, destined for the reception of "light" coin. If this next piece should be "too heavy," it will not only raise the counterpoise R but will also elevate a little wire S, which would otherwise remain undisturbed on a support. This little wire represents the "working remedy" for the particular denomination of coin in question, which for safety, is less by $\frac{1}{100}$th of a grain than the remedy permitted by law. The undue weight of the "heavy" coin will depress the right end of the balance beam and its pendant M to the lowest possible point, and the indicating finger T will in this case determine that the rod UU shall occupy the lowest step of the shoot V, which will consequently stand over the orifice W in the bottom plate of the balance which communicates with the receptacle for the "heavy" coins, and the heavy coin on the beam plate will be driven down the shoot by the next coin in succession. If the coin which is next brought forward by the slide H should be a "good" one, that is, if it is within the working "remedy," its action will be as follows. It may be slightly heavier than the counterpoise, but not sufficiently heavy to lift both the counterpoise and the remedy wire. The balance beam consequently remains approximately horizontal, and the indicating finger T will cause the rod UU to strike the centre step of the shoot V, which will then stand over the central orifice W in the bed plate which communicates with a receptacle for "good" coins, into which the coin will find its way as soon as it is driven from the beam plate by the next coin of the series. It will be evident that this excellent appliance both weighs and classifies the coins. About twenty-three coins are passed through it in a minute.

In order to show the importance of extreme accuracy in weighing, it may be pointed out that, although by the Coinage Act of 1870 the "remedy" or allowed variation above or below the standard weight of a sovereign is only $\frac{1}{5}$th of a grain, yet in a million sterling of sovereigns the difference between the least and the greatest weight the law allows would be no less than £3244.

The manufacture of coin is not the only work which is performed in the Royal Mint. All medals issued to the army and navy, as well as those given by the Royal Society and the university of London and some others, are struck in the mint, and their preparation forms a considerable part of the work of the die department. Since 1874 the clasps and bars for the medals have also been manufactured in the mint, whence they have been issued completely mounted. Another operation not connected with the coinage, which is performed in the mint is the assay of the "diet" or metal scraped from the gold and silver plate manufactured at Sheffield and Birmingham under the direction of the warden of the standard of wrought plate for those towns. By Act of Parliament it is directed that this shall be brought once in each year to the mint to be assayed by the "king's assay master," under the supervision of an officer appointed by the lords of the Treasury.

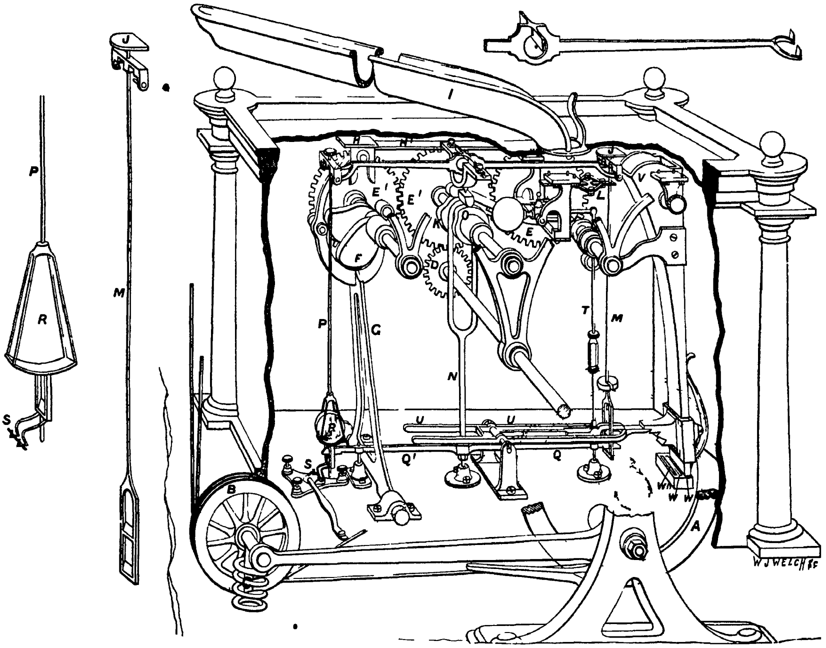


FIG. 13.—Automatic Balance.

The gold coin in circulation in Great Britain is estimated at £100,000,000. It may be well to add the following table, which gives the value of the gold and silver coinages of four of the most important foreign countries, in two recent years:—

United States	£12 461 655	£5 481,941	£19 370 178	£ [illegible]87 840
Germany	1 332 430			
Austria	493 605	1 674 712		
France				
	£14 287 690	£7 156 653	£20 260 060	£7 653 484

The value of the gold coinage of the American mints during the fiscal year ending June 1882 amounted to $89,413,447.50,—being greater than that of any previous year in their history. (W. C. R.—R. A. H.)

MINT, botanically *Mentha*, a genus of labiate plants comprising about twenty species of perennial herbs widely distributed throughout the temperate and sub-tropical portions of the globe. All the species are furnished with square stems, opposite, aromatic leaves, and creeping roots. The flowers are arranged in axillary cymes which either form separate whorls or are crowded together into a terminal spike. The corolla is usually small and of a pale purple or pinkish colour; it has four nearly equal lobes, and encloses two long and two short stamens. Great difficulty is experienced by botanists in discriminating the species of this genus by reason of the occurrence of a large number of intermediate forms, nearly three hundred of which have been named and described. Many of these varieties are permanent in consequence of being propagated by stolons.

In Britain nine of the recognized species are indigenous. *Mentha viridis*, L., or Spearmint, grows in marshy meadows, and is the species commonly used for culinary purposes; it is distinguished by its smooth sessile leaves and lax tapering flower spikes. *Mentha sylvestris*, L., or Horsemint, chiefly differs from the above in its coarser habit and hairy leaves which are silky beneath, and in its denser flower spikes. This plant is supposed to be the mint of Scripture, as it is extensively cultivated in the East, and is much used in cookery; it was one of the bitter herbs with which the paschal lamb was eaten. *M. rotundifolia* resembles the last in size and habit, but is readily distinguished by its rounded wrinkled leaves which are shaggy beneath and by its lanceolate bracts. The last two species usually grow on damp waste ground near roadsides. *M. aquatica*, or Capitate Mint, grows in ditches and by the side of streams, and is easily recognized by its rounded flower spikes and stalked hairy leaves. *M. Piperita*, or Peppermint has stalked smooth leaves and an oblong obtuse terminal spike of flowers; it is extensively culti vated for its volatile oil *M pratensis* belongs to a group of mints which, unlike the foregoing, have the flowers arranged in axillary whorls and never in terminal spikes, it otherwise bears some resemblance in foliage and habit to *M viridis* *M sativa*, the Whorled Hairy Mint, grows by damp roadsides, and *M arvensis* in cornfields they are distinguished from *M pratensis* by their hairy stalked leaves which in *M arvensis* are all equally large, but in *M. sativa* are much smaller towards the apex of the stem *M Pulegium*, commonly known as Pennyroyal more rarely as Flea mint, has small oval obtuse leaves and flowers in axillary whorls, and is remarkable for its creeping habit and peculiar odour It differs from all the mints above described in the throat of the calyx being closed with hairs It is met with in damp places on grassy commons, and forms a well known domestic remedy for female disorders

All the plants of the genus *Mentha* abound in a volatile oil, which is contained in small receptacles having the appearance of resinous dots in the leaves and stems The odour of the oil is similar in several species, but is not distinctive, the same odour occurring in varieties of distinct species, while plants which cannot be distinguished by any botanical character possess the same odour Thus the peppermint flavour is found in *M Piperita*, in *M incana*, and in Chinese and Japanese varieties of *M arvensis* Other forms of the last named species growing in Ceylon and Java have the flavour of the common garden mint, *M viridis*, and the same odour is found to a greater or less degree in *M sylvestris*, *M rotundifolia*, and *M canadensis* A bergamot scent is met with in a variety of *M aquatica* and in forms of other species Most of the mints may be found in blossom in August

The name mint is also applied to plants of other genera, *Monarda punctata* being called Horsemint, *Pycnanthemum linifolium*, Mountain Mint and *Nepeta Cataria*, Catmint

MINTO, Sir Gilbert Elliot, First Earl of (1751–1814), was descended from an old border family, the Elliots of Minto, and was born at Edinburgh, April 23, 1751 His father, Sir Gilbert Elliot, was a member of the administration of Pitt and Grenville, and is spoken of by Horace Walpole as "one of the ablest men in the House of Commons " Young Elliot was educated by a private tutor, with whom at the age of twelve he went to Paris, where David Hume, who was then secretary of the embassy, undertook, from friendship to his father, the special charge of superintending his studies After spending the winters of 1766 and 1767 at Edinburgh University, Elliot entered Oxford On quitting the university he became a member of Lincoln s Inn, and was in 1774 called to the bar He entered parliament in 1776, the year of his father s death Although he gave a general support to Lord North s administration, he from the beginning occupied an independent position, and in 1782 supported the address of the Commons against an offensive war with America From this time he became a declared follower of Fox and Burke, with the latter of whom he gradually came to be on terms of great intimacy He was created Baron Minto in 1797, and after filling several diplomatic posts with great success became in 1807 governor general of India The character and events of his rule in India are described in vol xii p 80) He was created Earl of Minto and Viscount Melgund in 1813 He returned to England in 1814, and died on June 21st of that year

See *Life and Letters of Sir Gilbert Elliot first Earl of Minto from* 1751 *to* 1806 1874 and *Life and Letters* 1807 14 1880 See also MIRABEAU

MINUCIUS FELIX, Marcus, one of the earliest, if not the earliest, of the Latin apologists for Christianity Of his personal history nothing is known, and even the date at which he wrote can be only approximately ascertained Jerome (*De Vir Ill*, 58) speaks of him as "Romæ insignis causidicus," but in this he is probably only improving on the expression of Lactantius (*Inst Div*, v 1) who speaks of him as "non ignobilis inter causidicos loci " He is now exclusively known by his *Octavius*, a dialogue on Christianity between the pagan Cæcilius Natalis[1] and the Christian Octavius Januarius, a provincial solicitor, the friend and fellow student of the author The scene is pleasantly and graphically laid on the beach at Ostia on a holiday afternoon, and the discussion is represented as arising out of the homage paid by Cæcilius, in passing, to the image of Serapis His arguments for paganism, which proceed partly upon agnostic grounds, partly upon the inexpediency of disturbing long established religious beliefs, partly upon the known want of culture in Christians, the alleged indecency of their worship, and the inherent absurdity of their doctrines, are taken up seriatim by Octavius, with the result that the assailant is convinced, postponing, however, the discussion of some things necessary for perfect instruction to a future occasion The form of the dialogue, modelled on the *De Natura Deorum* and *De Divinatione* of Cicero, shows much care and ability, and its style is on the whole both vigorous and elegant if at times not exempt from something of the affectations of the age If the doctrines of the Divine unity, the resurrection, and future rewards and punishments be left out of account, the work has less the character of an exposition of Christianity than of a philosophical and ethical polemic against the absurdities of crass polytheism Christology and the other metaphysics of distinctively Christian theology are entirely passed over, and the canonical Scriptures are not quoted, hardly even alluded to

The *Octavius* is admittedly earlier than Cyprian s *De Idolorum Vanitate* which borrows from it, how much earlier can be determined only by settling the relation in which it stands to Tertullian s *Apologeticum* The argument for the priority of Minucius has been most exhaustively set forth by Ebert ("Tertullians Verhaltniss zu Minucius Felix in vol v of the philologico historical series in *Abhandl d König Sachs Gesellsch der Wissenschaften* 1868) who has been followed by Teuffel (*Rom Lit*, sec 368), Keim (*Celsus Wahres Wort*, 1873) Kuhn and other scholars The opposite view is ably maintained by Professor Salmon (Minucius Felix in Smith's *Dict Christ Biogr* 1882) The *Octavius* was first printed (Rome, 1543) as the eighth book of Arnobius *Adv Gentes* Balduinus (Heidelberg 1560) first assigned it to its proper author There have been numerous subsequent editions, the best being that of Halm in the *Corp Scriptor Eccl Lat* (Vienna 1867) See Kuhn s monograph, *Der Octavius des Minucius Felix* (1882)

MINUET (Fr *Menuet*, from [*pas*] *menus*), a very graceful kind of dance, consisting of a coupee, a high step, and a balance Its invention is universally ascribed to the inhabitants of Poitou The melody begins with the down beat, and contains three crotchets in a bar The music is made up of two strains, which, from being repeated, are called *reprises*, each consisting of eight or more bars, but very rarely of an odd number Walther speaks of a minuet in Lully s opera of *Roland*, each strain of which contains ten bars, the sectional number being five,—a circumstance which renders it very difficult to be danced, but Lully's system of phrasing was remarkably irregular Modern instrumental composers have introduced into their symphonies and quartetts, &c, minuets of rapid movement and fanciful character, followed by supplementary strains (called trios) in a different style Some of these compositions bear but very slight resemblance to the older forms, and many of them begin with the third beat in the bar The finest minuets we possess are those in Handel's *Samson* and Mozart's *Don Giovanni*

MIRABEAU, Honoré Gabriel Riqueti, Comte de, (1749–1791), one of the greatest statesmen and orators

---

[1] This name occurs in six inscriptions of the years 211–217 found at Constantine (Cirta), North Africa (*C I L*, vol viii)

France has ever produced, was born at Bignon, near Nemours, on March 9, 1749. M. de Loménie has shown that the family of Riquet or Riqueti came originally from the little town of Digne, that they won wealth and municipal honours as merchants at Marseilles, and that in 1570 Jean Riqueti bought the chateau and estate of Mirabeau, which had up to that time belonged to the great Provencal family of Barras, and took the title of esquire a few years later. In 1685 Honoré Riqueti obtained the title of Marquis de Mirabeau, and his son Jean Antoine brought honour to it. He served with distinction through all the later campaigns of the reign of Louis XIV, and especially distinguished himself in 1705 at the battle of Cassano, where he was so severely wounded in the neck that he had ever after to wear a silver stock; yet he never rose above the rank of colonel, owing to his eccentric habit of speaking unpleasant truths to his superiors. On retiring from the service he married Françoise de Castellane, a remarkable woman, who long survived him, and he left at his death, in 1737, three sons—Victor, Marquis de Mirabeau (see next article), Jean Antoine, Bailli de Mirabeau, and Comte Louis Alexandre de Mirabeau. The great Mirabeau was the elder surviving son of the marquis. When but three years old he had a virulent attack of confluent small-pox which left his face for ever disfigured and contributed not a little to nourish his father's dislike to him. His early education was conducted by Lachabeaussière, father of the better known man of letters, after which, being like his father and grandfather destined for the army, then the only profession open to young men of family, he was entered at a pension militaire at Paris, kept by an Abbé Choquart. Of this school, which had Lagrange for its professor of mathematics, we have an amusing account in the life of Gilbert Elliot, first earl of Minto, who with his brother Hugh, afterwards British minister at Berlin, there made the acquaintance of Mirabeau, an acquaintance which soon ripened into friendship, and to which Mirabeau in later life owed his introduction into good English society. On leaving this school in 1767 he received a commission in the cavalry regiment of the Marquis de Lambert, which his grandfather had commanded years before. He at once began love-making, and in spite of his ugliness succeeded in winning the heart of the lady to whom his colonel was attached, which led to such scandal that his father obtained a lettre de cachet, and the young scapegrace was imprisoned in the isle of Rhé. The love affairs of Mirabeau form quite a history by themselves, and a well-known history, owing to the celebrity of the letters to Sophie; and the behaviour of the marquis in perpetually imprisoning his son is equally well known, and as widely blamed. Yet it may be asserted that until the more durable and more reputable connexion with Madame de Nehra these love episodes were the most disgraceful blemishes in a life otherwise of a far higher moral character than has been commonly supposed. As to the marquis, his use of lettres de cachet is perfectly defensible on the theory of the existence of lettres de cachet at all. They were meant to be used (see LETTRES DE CACHET) by heads of families for the correction of their families, and Mirabeau, if any son, surely deserved such correction. Further, they did have the effect of sobering the culprit, and the more creditable part of his life did not begin till he left Vincennes. Mirabeau, it may be remarked at once, was not a statesman of the Alcibiades type, and he did not develop his great qualities of mind and character until his youthful excesses were over. These will be passed over as rapidly as possible, for it was not till 1781 that the qualities which made him great began to appear.

On being released from his first imprisonment, the young count, who had always intended to continue his military career, obtained leave to accompany as a volunteer the French expedition which was to effect the reduction of Corsica. The conquest was one of sheer numerical strength, for the whole population was on the side of Paoli, and Mirabeau, perceiving the value of public opinion, is said to have written a treatise on the oppression the Genoese had formerly exercised over the island, which the Government was ready to publish had not the Marquis de Mirabeau thought fit to destroy it because of its divergence from his own philosophical and economical views. For his services in Corsica Mirabeau was made a captain of dragoons, though not in any particular regiment, and on his return his father endeavoured to make use of the literary ability he had shown for the advancement of his own economical theories. He tried to keep on good terms with his father, though he could not advocate all his ideas, and even went so far in 1772 as to marry a rich heiress, a daughter of the Marquis de Marignane, whose alliance his father had procured for him. He did not live happily with her, and in 1774 was ordered into semi-exile in the country at his father's request, where he wrote his earliest extant work, the *Essai sur le Despotisme*. His violent disposition now led him to quarrel with a country gentleman who had insulted his sister, and his semi-exile was changed by lettre de cachet into imprisonment in the Chateau d'If. In 1775 he was removed to the castle of Joux, to which, however, he was not very closely confined, having full leave to visit in the town of Pontarlier. Here he met Marie Thérèse de Monnier, his Sophie as he called her, a married woman for whom he conceived a violent passion. Of his behaviour nothing too strong can be said: he was introduced into the house as a friend, and betrayed his trust by inducing Madame de Monnier to fall in love with him, and all his excuses about overwhelming passion only make his conduct more despicable. The affair ended by his escaping to Switzerland, where Sophie joined him; they then went to Holland, where he lived by hack work for the booksellers; meanwhile Mirabeau had been condemned to death at Pontarlier for *rapt et vol*, of which he was certainly not guilty, as Sophie had followed him of her own accord, and in May 1777 he was seized by the French police, and imprisoned by a lettre de cachet in the castle of Vincennes. There he remained three years and a half, and with his release ends the first and most disgraceful period of his life. During his imprisonment he seems to have learnt to control his passions from their very exhaustion, for the early part of his confinement is marked by the indecent letters to Sophie (first published in 1793) and the obscene *Erotica Biblion* and *Ma Conversion*, while to the later months belongs his first political work of any value, the *Lettres de Cachet*. The *Essai sur le Despotisme* was an ordinary but at times eloquent declamation, showing in its illustrations a wide miscellaneous knowledge of history, but the *Lettres de Cachet* exhibits a more accurate knowledge of French constitutional history skilfully applied to an attempt to show that an existing actual grievance was not only philosophically unjust but constitutionally illegal. It shows, though still in rather a diffuse and declamatory form, that application of wide historical knowledge, keen philosophical perception, and genuine eloquence to a practical purpose which was the great characteristic of Mirabeau both as a political thinker and as a statesman.

With his release from Vincennes begins the second period of Mirabeau's life. He found that his Sophie was an idealized version of a rather common and ill-educated woman, and she speedily consoled herself with the affection of a young officer, after whose death she committed suicide. Mirabeau first set to work to get the sentence of death still hanging over him reversed, and by his eloquence not only succeeded but got M. de Monnier condemned in the costs of the whole law proceedings. From Pontarlier he went to Aix, where he claimed the court's order that his wife should return to him. She naturally objected, but his eloquence would have won his case, even against Portalis, the leader of the Aix bar, had he not in his excitement accused his wife of infidelity, on which the court pronounced a decree of separation. He then with his usual impetuosity intervened in the suit pending between his father and mother before the parlement of Paris, and so violently attacked the ruling powers that he had to leave France and again go to Holland, and try to live by literary work. About this time began his connexion with Madame de Nehra, which sweetened the ensuing years of toil and brought out the better points of his character. She was the daughter of Zwier van Haren, a Dutch statesman and political writer, and was a woman of a far higher type than Sophie, more educated, more refined, and more capable of appreciating Mirabeau's good points and helping him to control his passions. With her the lion became a lamb, and his life was strengthened by the love of his *petite horde*, Madame de Nehra, her baby son, afterwards Lucas de Montigny, and his little dog Chico. After a period of work in Holland he betook himself to England, where his treatise on *Lettres de Cachet* had been much admired, and where he was soon admitted into the best Whig literary and political society of London, through his old schoolfellow Gilbert Elliot, who had now inherited his father's baronetcy and estates, and become a leading Whig member of parliament. Sir Gilbert introduced him freely, but of all his English friends none seem to have been so intimate with him as Lord Lansdowne, and Mr (afterwards Sir Samuel) Romilly. The latter became particularly attached to him, and really understood his character; and it is strange that his remarks upon Mirabeau in the fragment of autobiography which he left, and Mirabeau's letters to him, should have been neglected by French writers. Romilly was introduced to Mirabeau by D'Ivernois, and readily undertook to translate the *Considerations on the Order of Cincinnatus*. Romilly writes thus of him in his autobiography:—

> 'The count was difficult enough to please; he was sufficiently impressed with the beauties of the original. He went over every part of the translation with me, observed on every passage in which justice was not done to the thought, or the force of the expression lost, and made many useful criticisms. During this occupation we had occasion to see one another often, and became very intimate; and as he had read much, had seen a great deal of the world, was acquainted with all the most distinguished persons who at that time adorned either the royal court or the republic of letters in France, had a great knowledge of French and Italian literature, and possessed very good taste, his conversation was extremely interesting and not a little instructive. I had such frequent opportunities of seeing him at this time, and afterwards at a much more important period of his life, that I think his character was well known to me. I doubt whether it has been so well known to the world; and I am convinced that great injustice has been done him. This indeed is not surprising, when one considers that from the first moment of his entering upon the career of an author, he had been altogether indifferent how numerous or how powerful might be the enemies he should provoke. His vanity was certainly excessive, but I have no doubt that in his public conduct as well as in his writings he was desirous of doing good, that his ambition was of the noblest kind, and that he proposed to himself the noblest ends. He was however, like many of his countrymen who were active in the calamitous Revolution which afterwards took place, not sufficiently scrupulous about the means by which those ends were to be accomplished. He indeed [illegible] professed this, and more than once I have heard him say that there were occasions upon which 'la petite morale était ennemie de la grande.' It is not surprising that with such maxims as these in his mouth, unguarded in his expressions, and careless of his reputation, he should have afforded room for the circulation of many stories to his disadvantage. Violent, impetuous, conscious of the superiority of his talents, and the declared enemy and denouncer of every species of tyranny and oppression, he could not fail to shock the prejudices, to oppose the interests, to excite the jealousy, and to wound the pride of many descriptions of persons. A mode of refuting his works, open to the basest and vilest of mankind, was to represent
>
> ice set on
>
> no malice
>
> extraordinary; and what more extraordinary than a person so admirable for his talents and so contemptible for his conduct, professing in his writings principles so excellent and in all the offices of public and private life putting in practice those which are so detestable? I indeed possessed demonstrative evidence of the falsehood of some of the anecdotes which by men of high character were related to his prejudice.—*Life of Sir S. Romilly*, vol. i. p. 58.

This luminous judgment, the best that is extant on the character of Mirabeau, deserved to be quoted at length; it must be noted that it was written by a man of acknowledged purity of life, who admired Mirabeau in early life not when he was a statesman, but when he was only a struggling literary man. This close association with Romilly, and his friends Baynes, Trail, and Wilson, does credit to Mirabeau, and must have helped that moral revolution against his passions which was passing within him. He was a warm friend, and first made Romilly acquainted with Lord Lansdowne, and tried to get him a seat in parliament. Lord Lansdowne was himself an extraordinary man, and the first of the new Whigs might well feel sympathy with the statesman of the French Revolution. The *Considérations sur l'ordre de Cincinnatus* which Romilly translated was the only important work Mirabeau wrote in the year 1785, and it is a good specimen of his method. He had read a pamphlet published in America attacking the proposed order, which was to form a bond of association between the officers who had fought in the American War of Independence against England; the arguments struck him as true and valuable, so he rearranged them in his own fashion, and rewrote them in his own oratorical style. He soon found such work not sufficiently remunerative to keep his "petite horde" in comfort, and then turned his thoughts to employment from the French foreign office either in writing or in diplomacy. He first sent Madame de Nehra to Paris to make his peace with the authorities, in which she was completely successful, and then returned himself, hoping to get employment through an old literary collaborateur of his, Durival, who was at this time director of the finances of the department of foreign affairs. One of the functions of this official was to subsidize political pamphleteers, and Mirabeau had hoped to be so employed, but he ruined his chances by a series of financial works. On his return to Paris he had become acquainted with Clavières, a Genevese exile, who was minister of finance during the Revolution, and who now introduced him to a banker named Panchaud. From them he heard plenty of abuse of stock jobbing, and seizing their ideas he began to regard stock jobbing, or agiotage, as the source of all evil, and to attack in his usual vehement style the Banque de St Charles and the Compagnie des Eaux. This was at least disinterested on his part, for, while his supporters were poor, the bankers he attacked were rich, and would gladly have bought his silence; but Mirabeau, though ever ready to take money for what he wrote, never sold his opinions, or wrote what he did not really believe. The very eloquence of his style rests upon the enthusiastic conviction that he himself was right, and those who differed from him were stupidly and wilfully wrong. This last pamphlet brought him into a controversy with Beaumarchais, who certainly did not get the best of it, but it lost him any chance of literary employment from Government. However, his ability was too great to be neglected by a great minister such as M. de Vergennes undoubtedly was, and after a preliminary tour in the early spring of 1786 he was despatched in June 1786 on a secret mission to the court of Prussia, from which he returned in January 1787, and of which he gave a full account in his *Histoire Secrète de la Cour de Berlin*.

The months he spent at Berlin were important ones in the history of Prussia, for in them Frederick the Great died The letters just mentioned show clearly what Mirabeau did and what he saw, and equally clearly how unfit he was to be a diplomatist, for, with all his knowledge of men and his influence over them, he thought (and showed he thought) too much of himself ever to be able to surprise their secret thoughts and intentions He certainly failed to conciliate the new king Frederick William and thus ended Mirabeau s one attempt at diplomacy During his journey he had made the acquaintance of a Major Mauvillon, whom he found possessed of a great number of facts and statistics with regard to Prussia these he made use of in a great work on Prussia published in 1788, as Romilly says, to show that he could write more than a fugitive pamphlet But, though his *Monarchie Prussienne* gave him a general reputation for historical learning he had in this same year lost a chance of political employment He had offered himself as a candidate for the office of secretary to the Assembly of Notables which the king had just convened, and to bring his name before the public published another financial work the *Denonciation de l Agiotage*, dedicated to the king and notables which abounded in such violent diatribes that he not only lost his election but was obliged to retire to Tongres and he further injured his prospects by publishing the reports he had sent in during his secret mission at Berlin But 1789 was at hand the states general was summoned Mirabeau s period of probation was over and he was at last to have that opportunity of showing his great qualities both as statesman and orator on a worthy arena

On hearing of the king s determination to summon the states general Mirabeau started for Provence, and offered to assist at the preliminary conference of the noblesse of his district They rejected him he appealed to the *tiers etat*, and was returned both for Aix and for Marseilles He elected to sit for the former city and was present at the opening of the states general on May 4 1789 From this time the record of Mirabeau s life forms the best history of the first two years of the Constituent Assembly for at every important crisis his voice is to be heard, though his advice was not always followed It is impossible here to detail minutely the history of these two eventful years it will be rather advisable to try and analyse the manner in which Mirabeau regarded passing events, and then show how his policy justifies our analysis

Mirabeau possessed at the same time great logical acuteness and most passionate enthusiasm he was therefore both a statesman and an orator and the interest of the last two years of his life lies mainly in the gradual but decided victory of the statesmanlike and practical over the impulsive and oratorical qualities From the beginning Mirabeau recognized that government exists in order that the bulk of the population may pursue their daily work in peace and quiet, and that for a Government to be successful it must be strong In this practical view of the need of a strong executive lies one of Mirabeau s greatest titles to the name of statesman At the same time he thoroughly comprehended that for a Government to be strong it must be in harmony with the wishes of the majority of the people and that the political system of Louis XIV was now falling for lack of this He had carefully studied the English constitution in England under the guidance of such men as Lord Lansdowne, Sir Gilbert Elliot and Romilly and appreciated it with the wise approval of its powers of expansion which characterized the new Whigs, and not with the blind admiration of Burke He understood the key notes of the practical success of the English constitution to be the irresponsibility of the king the solidarity of the ministers, and the selection of the executive from among the majority of the representatives of the country, and he hoped to establish in France a system similar in principle, but without any slavish imitation of the details of the English constitution

In the first stage of the history of the states general Mirabeau s part was very great He was soon recognized as a leader, to the chagrin of Mounier, because he always knew his own mind, and was prompt at emergencies To him is to be attributed the successful consolidation of the National Assembly, its continuance in spite of De Brezé and the carpenters, and the address to the king for the withdrawal of the troops assembled by De Broglie When the taking of the Bastille had assured the success of the Revolution, he was the one man who warned the Assembly of the futility of passing fine sounding decrees and the necessity for acting He declared that the famous night of August 4 was but an orgy, giving the people an immense theoretical liberty while not assisting them to practical freedom, and overthrowing the old regime before a new one could be constituted Still more did he show his foresight when he attacked the dilatory behaviour of the Assembly, which led to the catastrophes of the 5th and 6th October He implored the Assembly to strike while the iron was hot and at once solve in a practical manner the difficult problems presented by the abolition of feudalism But the Assembly consisted of men inexperienced in practical politics, who dreamed of drawing up an ideal constitution preluded by a declaration of rights in imitation of the Americans and for two months the Assembly discussed in what words the declaration should be expressed while the country was in a state of anarchy, declaring old laws and customs abolished and having no new ones to obey or follow, disowning the old administrative system and having no new one yet instituted, while Paris was starving and turbulent and the queen and her friends planning a counter revolution The result of these two months theorizing was the march of the women to Versailles, and the transfer of the king to Paris Mirabeau now saw clearly that his eloquence would not enable him to guide the Assembly by himself, and that he must therefore try to get some support He wished to establish a strong ministry, which should be responsible like an English ministry but to an assembly chosen to represent the people of France better than the English House of Commons then represented England He first thought of becoming a minister at a very early date, if we may believe a story contained in the *Memoires* of the Duchesse d Abrantes to the effect that in May 1789 the queen tried to bribe him but that he refused to be bribed to silence, and expressed his wish to be a minister The indignation with which the queen repelled the idea may have been the cause of his thinking of the Duc d Orleans as a possible constitutional king because his title would of necessity be parliamentary But the weakness of Orleans was too palpable, and in a famous remark Mirabeau expressed his utter contempt for him He also attempted to form an alliance with Lafayette, but the general was as vain and as obstinate as Mirabeau himself, and had his own theories about a new French constitution Mirabeau tried for a time, too, to act with Necker, and obtained the sanction of the Assembly to Necker s financial scheme, not because it was good but because, as he said, "no other plan was before them, and something must be done

Hitherto weight has been laid on the practical side of Mirabeau's political genius his ideas with regard to the Revolution after the 5th and 6th October must now be examined, and this can be done at length thanks to the publication of Mirabeau s correspondence with La Marck, a study of which is indispensable for any correct knowledge of the history of the Revolution between 1789 and 1791

The Comte de la Marck was a Flemish lord of the house of Aremberg, who had been proprietary colonel of a regiment in the service of France; he was a close friend of the queen, and had been elected a member of the states-general. His acquaintance with Mirabeau, commenced in 1788, ripened during the following year into a friendship, which La Marck hoped to turn to the advantage of the court. After the events of the 5th and 6th of October he consulted Mirabeau as to what measures the king ought to take, and Mirabeau, delighted at the opportunity, drew up an admirable state paper, which was presented to the king by Monsieur, afterwards Louis XVIII. The whole of this *Mémoire* should be read to get an adequate idea of Mirabeau's genius for politics; here it must be merely summarized.

The main position is that the king is not free in Paris; he must therefore leave Paris and appeal to France. "Paris n'en veut qu'à l'argent; les provinces demandent les lois." But where must the king go? "Se retirer à Metz ou sur toute autre frontière serait déclarer la guerre à la nation et abdiquer le trône. Un roi qui est la seule sauvegarde de son peuple ne fuit point devant son peuple; il le prend pour juge de sa conduite et de ses principes." He must then go towards the interior of France to a provincial capital, best of all to Rouen, and there he must appeal to the people and summon a great convention. It would be ruin to appeal to the noblesse as the queen advised; "un corps de noblesse n'est point une armée qui puisse combattre." When this great convention met, the king must show himself ready to recognize that great changes have taken place, that feudalism and absolutism have for ever disappeared, and that a new relation between king and people has arisen, which must be loyally observed on both sides for the future. "Il est certain, d'ailleurs, qu'il faut une grande révolution pour sauver le royaume; que la nation a des droits, qu'elle est en chemin de les recouvrer tous, et qu'il faut non seulement les rétablir mais les consolider." To establish this new constitutional position between king and people would not be difficult, because "l'indivisibilité du monarque et du peuple est dans le cœur de tous les Français; il faut qu'elle existe dans l'action et le pouvoir."

Such was Mirabeau's programme, which he never diverged from, but which was far too statesmanlike to be understood by the poor king, and far too positive as to the altered condition of the monarchy to be palatable to the queen. Mirabeau followed up his *Mémoire* by a scheme of a great ministry to contain all men of mark,—Necker as prime minister, "to render him as powerless as he is incapable, and yet preserve his popularity for the king," the archbishop of Bordeaux, the Duc de Liancourt, the Duc de la Rochefoucauld, La Marck, Talleyrand bishop of Autun at the finances, Mirabeau without portfolio, Target mayor of Paris, Lafayette generalissimo to reform the army, Ségur (foreign affairs), Mounier, and Chapelier. This scheme got noised abroad, and was ruined by a decree of the Assembly of November 7, 1789, that no member of the Assembly could become a minister; this decree destroyed any chance of that necessary harmony between the ministry and the majority of the representatives of the nation existing in England, and so at once overthrew Mirabeau's present hopes and any chance of the permanence of the constitution then being devised. The queen utterly refused to take Mirabeau's counsel, and La Marck left Paris. However, in April 1790 he was suddenly recalled by the Comte de Mercy-Argenteau, the Austrian ambassador at Paris, and the queen's most trusted political adviser, and from this time to Mirabeau's death he became the medium of almost daily communications between the latter and the queen. Mirabeau at first attempted again to make an alliance with Lafayette by a letter in which he says, "Les Barnave, les Duport, les Lameth ne vous fatiguent plus de leur active inaction; on singe longtemps l'adresse, non pas la force." But it was useless to appeal to Lafayette; he was not a strong man himself, and did not appreciate "la force" in others. From the month of May 1790 to his death in April 1791 Mirabeau remained in close and suspected but not actually proved connexion with the court, and drew up many admirable state papers for it. In return the court paid his debts; but it ought never to be said that he was bribed, for the gold of the court never made him swerve from his political principles—never, for instance, made him a royalist. He regarded himself as a minister, though an unavowed one, and believed himself worthy of his hire. Undoubtedly his character would have been more admirable if he had acted without court assistance, but it must be remembered that his services deserved some reward, and that by remaining at Paris as a politician he had been unable to realize his paternal inheritance. Before his influence on foreign policy is discussed, his behaviour on several important points must be noticed. On the great question of the veto he took a practical view, and seeing that the royal power was already sufficiently weakened, declared for the king's absolute veto, and against the compromise of the suspensive veto. He knew from his English experiences that such a veto would be hardly ever used unless the king felt the people were on his side, in which case it would be a useful check on the representatives of the people, and also that if it was used unjustifiably the power of the purse possessed by the representatives and the very constitutional organization of the people would, as in England in 1688, bring about a bloodless revolution, and a change in the person entrusted with the royal dignity. He saw also that much of the inefficiency of the Assembly arose from the inexperience of the members, and their incurable verbosity; so, to establish some system of rules, he got his friend Romilly to draw up a detailed account of the rules and customs of the English House of Commons, which he translated into French, but which the Assembly, puffed up by a belief in its own merits, refused to use. On the great subject of peace and war he supported the king's authority, and with some success. What was the good of an executive which had no power? Let it be responsible to the representatives of the nation by all means; but if the representatives absorbed all executive power by perpetual interference, there would be six hundred kings of France instead of one, which would hardly be a change for the better. Again Mirabeau almost alone of the Assembly understood the position of the army under a limited monarchy. Contrary to the theorists, he held that the soldier ceased to be a citizen when he became a soldier; he must submit to be deprived of his liberty to think and act, and must recognize that a soldier's first duty is obedience. With such sentiments, it is no wonder that he approved of Bouillé's vigorous conduct at Nancy, which was the more to his credit as Bouillé was the one hope of the court influences opposed to him. Lastly, in matters of finance he showed his wisdom; he attacked Necker's "caisse d'escompte," which was to have the whole control of the taxes, as absorbing the Assembly's power of the purse; and he heartily approved of the system of assignats, but with the important reservation that they should not be issued to the extent of more than one half the value of the lands to be sold. This restriction was not observed, and it was solely the enormous over-issue of assignats that caused their great depreciation in value.

Of Mirabeau's attitude with regard to foreign affairs it is necessary to speak in more detail. He held it to be just that the French people should conduct their Revolution as they would, and that no foreign nation had any right to interfere with them so long as they kept themselves strictly to their own affairs. But he knew also that neighbouring nations looked with unquiet eyes on the progress of affairs in France, that they feared the influence of the Revolution on their own peoples, and that foreign monarchs were being prayed by the French émigrés to interfere on behalf of the French monarchy. To prevent this interference, or rather to give no pretext for it, was his guiding thought as to foreign policy. He had been elected a member of the comité diplomatique of the Assembly in July 1790, and became its reporter at once, and in this capacity he was able to prevent the Assembly from doing much harm in regard to foreign affairs. He had long known Montmorin, the foreign secretary, and, as matters became more strained from the complications with the princes and counts of the empire, he entered into daily communication with the minister, advised him on every point, and, while dictating his policy, defended it in the Assembly. Thus in this particular instance of the foreign office, for the few months before Mirabeau's death, a harmony was established between the minister and the Assembly through Mirabeau, which checked for a time the threatened approach of foreign intervention, and maintained the honour of France abroad. Mirabeau's exertions in this respect are not his smallest title to the name of statesman, and how great a work he did is best proved by the confusion which ensued in this department of affairs upon his death.

For indeed in the beginning of 1791 his death was very near, and he knew it to be so. The wild excesses of his youth and their terrible punishment had weakened his strong constitution, and his parliamentary labours completed the work. So surely did he feel its approach that some time before the end he sent all his papers over to his old English friend and schoolfellow Sir Gilbert Elliot, who kept them under seal until claimed by Mirabeau's executors. In March his illness was evidently gaining on him, to his great grief, because he knew how much depended on his life, and felt that he alone could yet save France from the distrust of her monarch and the present reforms, and from the foreign interference, which would assuredly bring about catastrophes unparalleled in the history of the world. On his life hung the future course of the Revolution. Every care that science could afford was given by his friend and physician, the famous chemist Cabanis, to whose brochure on his last illness and death the reader may refer. The people, whose faith in him revived in spite of all suspicions, when they heard that he was on his death bed, kept the street in which he lay quiet; but medical care, the loving solicitude of friends, and the respect of all the people could not save his life. His vanity appears in its most gigantic proportions in his last utterances during his illness, but many of them have something grand in their sound, as his last reported expression, when he looked upon the sun—"If he is not God, he is at least His cousin german." When he could speak no more he wrote with a feeble hand the one word "dormir," and on April 2, 1791, he died.

With Mirabeau died, it has been said, the last hope of the monarchy, but, with Marie Antoinette supreme at court, can it be said that there could ever have been any real hope for the monarchy? Had she been but less like her imperious mother, Louis would have made a constitutional monarch, but her will was as strong as Mirabeau's own, and the Bourbon monarchy had to meet its fate. The subsequent events of the Revolution justified Mirabeau's prognostications in his first memoire of October 15, 1789. The royal family fled towards the German frontier, and from that moment there sunk deep into the hearts of the people not only of Paris but of the provinces a conviction that the king and queen were traitors to France, which led inevitably to their execution. The noblesse and the foreign aid on which the queen relied proved but a source of weakness. The noblesse, Mirabeau had said, was no army which could fight, and truly the army of the emigrés could do nothing against revolutionary France in arms. The intervention of foreign aid only sealed the king's fate, and forwarded the progress of the Revolution, not in a course of natural development, but to the terrible resource of the Reign of Terror. With regard to the Assembly too, and its constitution, Mirabeau had shown his foresight. The constitution of 1791, excellent as it was on paper, and well adapted to an ideal state, did not deal adequately with the great problems of the time in France, and by its ridiculous weakening of the executive was unsuited to a modern state. Surely if events ever proved a man's political sagacity, the history of the French Revolution proved Mirabeau's.

A few words must be added on Mirabeau's manner of work and his character.

No man ever so thoroughly used other men's work, and yet made it all seem his own. "Je prends mon bien où je le trouve" is as true of him as of Molière. His first literary work, except the bombastic but eloquent *Essai sur le Despotisme*, was a translation of Watson's *Philip II.*, accomplished in Holland with the help of Durival; his *Considérations sur l'ordre de Cincinnatus* was based on an American pamphlet, and the notes to it were contributed by Target; while his financial writings were all suggested by the Genevese exile Clavières. During the Revolution he received yet more help; men were proud to labour for him, and did not murmur because he absorbed all the credit and fame. Dumont, Clavières, Duroveray, Pellenc, Lamourette and Reybaz were but a few of the most distinguished of his collaborators. Dumont was a Genevese exile and an old friend of Romilly's, who willingly prepared for him those famous addresses which Mirabeau used to make the Assembly pass by sudden bursts of eloquent declamation. Clavières and Duroveray helped him in finance, and not only worked out his figures but even wrote his financial discourses. Pellenc was his secretary, and wrote the speeches on the goods of the clergy and the right of making peace; and even the Abbé Lamourette wrote the speeches on the civil constitution of the clergy. Reybaz, whose personality has only been revealed within these last ten years, not only wrote for him his famous speeches on the assignats, the organization of the national guard, &c., which Mirabeau read word for word at the tribune, but even the posthumous speech on succession to estates of intestates which Talleyrand read in the Assembly as the last work of his dead friend. Yet neither the gold of the court nor another man's conviction would make Mirabeau say what he did not himself believe, or do what he did not himself think right. He took other men's labour as his due, and impressed their words, of which he had suggested the underlying ideas, with the stamp of his own individuality; his collaborators themselves did not complain—they were but too glad to be of help in the great work of controlling and forwarding the French Revolution through its greatest thinker and orator. True is that remark of Goethe's to Eckermann after reading Dumont's *Souvenirs*: "At last the wonderful Mirabeau becomes natural to us, while at the same time the hero loses nothing of his greatness. Some French journalists think differently. The French look upon Mirabeau as their Hercules, and they are perfectly right. But they forget that even the Colossus consists of individual parts, and that the Hercules of antiquity is a collective being—a gigantic personification of deeds done by himself and by others."

There was something gigantic about all Mirabeau's thoughts and deeds. The excesses of his youth were beyond all bounds, and severely were they punished; his vanity was immense, but never spoilt his judgment; his talents were enormous, but could yet make use of those of others. As a statesman his wisdom is indubitable, but by no means universally recognized in his own country. Lovers of the *ancien régime* abuse its most formidable and logical opponent; believers in the Constituent Assembly cannot be expected to care for the most redoubtable adversary of their favourite theorists, while admirers of the republic of every description agree in calling him from his connexion with the court the traitor Mirabeau. As an orator more justice has been done him; his eloquence has been likened to that of both Bossuet and Vergniaud, but it had neither the polish of the old 17th century bishop nor the flashes of genius of the young Girondin. It was rather parliamentary oratory in which he excelled, and his true compeers are rather Burke and Fox than any French speakers. Personally he had that which is the truest mark of nobility of mind, a power of attracting love, and winning faithful friends. "I always loved him," writes Sir Gilbert Elliot to his brother Hugh; and Romilly, who was not given to lavish praise, says, "I have no doubt that in his public conduct, as in his writings, he was desirous of doing good, that his ambition was of the noblest kind, and that he proposed to himself the noblest ends." What more favourable judgment could be passed on an ambitious man! What finer epitaph could a statesman desire!

The best edition of Mirabeau's works is that published by Blanchard in 1822, in 10 vols., of which two contain his *Œuvres Oratoires*; from this collection, however, many of his less important works, and the *Monarchie Prussienne* in 4 vols., 1788, are omitted. For his life consult *Mirabeau, Mémoires sur sa vie littéraire et privée*, 4 vols., 1824, and what is of most importance, *Mémoires biographiques, littéraires et politiques de Mirabeau écrits par lui-même, par son père, son oncle et son fils adoptif*, which was issued by M. Lucas de Montigny in 8 vols., Paris, 1834. See also Dumont, *Souvenirs sur Mirabeau*, 1832; Duval, *Souvenirs sur Mirabeau*, 1832; Victor Hugo, *Étude sur Mirabeau*, 1834; *Mirabeau's Jugendleben*, Breslau, 1838; Schneidewin, *Mirabeau und seine Zeit*, Leipsic, 1831; *Mirabeau, a Life History*, London, 1848. The publication of the *Correspondance entre Mirabeau et le Comte de la Marck* by Ad. Bacourt, 2 vols., 1851, marks an epoch in our exact knowledge of Mirabeau and his career. The most useful modern books are Louis de Loménie, *Les Mirabeau*, 1878, which however chiefly treats of his father and uncle; Ph. Plan, *Un Collaborateur de Mirabeau*, 1874, treating of Reybaz and throwing infinite light on Mirabeau's mode of work; and lastly, H. Reynald, *Mirabeau et la Constituante*, 1872. On his eloquence and the share his collaborators had in his speeches see Aulard, *L'Assemblée Constituante*, 1882. For his death see the curious brochure of his physician Cabanis, *Journal de la maladie et de la mort de Mirabeau*, Paris, 1791. (H. M. S.)

MIRABEAU, Victor Riqueti, Marquis de (1715–1789), himself a distinguished author and political economist, but more famous as the father of the great Mirabeau, was born at Pertuis near the old chateau de Mirabeau on October 4, 1715 He was brought up very sternly by his father, and in 1729 joined the army He took keenly to campaigning but never rose above the rank of captain, owing to his being unable to get leave at court to buy a regiment In 1737 he came into the family property on his father's death, and spent some pleasant years till 1743 in literary companionship with his dear friends Vauvenargues and Lefranc de Pompignan, which might have continued had he not suddenly determined to marry—not for money, but for landed estates The lady whose property he fancied was Marie Genevieve, daughter of a M de Vassan, a brigadier in the army, and widow of the Marquis de Saulvebœuf, whom he married without previously seeing her on April 21, 1743 While in garrison at Bordeaux, Mirabeau had made the acquaintance of Montesquieu, which may have made him turn his thoughts to political speculations anyhow it was while at leisure after retiring from the army that he wrote his first work, his *Testament Politique* (1747), which demanded for the prosperity of France a return of the French noblesse to their old position in the Middle Ages This work, written under the influence of the feudal ideas impressed upon him by his father, was followed in 1750 by a book on the *Utilite des Etats Provenciaux*, full of really wise considerations for local self government, which was published anonymously, and had the honour of being attributed to Montesquieu himself In 1756 Mirabeau made his first appearance as a political economist by the publication of his *Ami des Hommes ou traite de la population* This work has been often attributed to the influence, and in part even to the pen, of Quesnay, the founder of the economical school of the physiocrats, but was really written before the marquis had made the acquaintance of the physician of Madame de Pompadour In 1760 he published his *Theorie de l'Impot*, in which he attacked with all the vehemence of his son the farmers general of the taxes, who got him imprisoned for eight days at Vincennes, and then exiled to his country estate at Bignon At Bignon the school of the physiocrats was really established, and the marquis surrounded himself with devotees, and eventually in 1765 bought the *Journal de l'agriculture du commerce, et des finances*, which became the organ of the school He was distinctly recognized as a leader of political thinkers by Prince Leopold of Tuscany, afterwards emperor, and by Gustavus III of Sweden, who in 1772 sent him the grand cross of the order of Vasa But the period of his happy literary life was over, and his name was to be mixed up in a long scandalous lawsuit Naturally his marriage had not been happy, he had separated from his wife by mutual consent in 1762, and had, he believed, secured her safely in the provinces by a lettre de cachet, when in 1772 she suddenly appeared in Paris, and soon after commenced proceedings for a separation The poor marquis did not know what to do his sons were a great trouble to him and it was one of his own daughters who had encouraged his wife to take this step Yet he was determined to keep the case quiet if possible for the sake of Madame de Pailly a Swiss lady whom he had loved since 1756 But his wife would not let him rest her plea was rejected in 1777, but she renewed her suit, and though the great Mirabeau had pleaded his father's case, was successful in 1781, when a decree of separation was pronounced This trial had quite broken the health of the marquis as well as his fortune he sold his estate at Bignon, and hired house at Argenteuil, where he lived quietly till his death on July 11, 1789.

For the whole family of Mirabeau, the one book to refer to is Louis de Lomenie's *Les Mirabeau*, 2 vols, 1878, and it is greatly to be regretted that the talented author did not live to treat the lives of the great Mirabeau and his brother See also Lucas de Montigny's *Memoires de Mirabeau*, and, for the marquis's economical views, De la Vergne's *Économistes français du* 18^{me} *siècle*

MIRAGE See Light, vol xiv p 600

MIRAMON, Miguel, a Mexican soldier of French extraction, was born in the city of Mexico, September 29, 1832, and shot along with the emperor Maximilian at Queretaro, June 19, 1867 While still a student he helped to defend the military academy at Chapultepec against the forces of the United States, and, entering the army in 1852, he rapidly came to the front during the civil wars that disturbed the country It was largely due to Miramon's support of the ecclesiastical party against Alvarez and Comonfort that Zuloaga was raised to the presidency, and in 1859 he was called to succeed him in that office Decisively beaten, however, by the Liberals, he fled the country in 1860, and spent some time in Europe earnestly advocating foreign intervention in Mexican affairs, and when he returned it was as a partisan of Maximilian His ability as a soldier was best shown by his double defence of Puebla in 1856

MIRANDA, Francesco (1754–1816), was born at Santa Fe in New Granada in 1754 He entered the army, and served against the English in the American War of Independence The success of that war inspired him with a hope of being the Washington of his own country, and a belief that the independence of Spanish America would increase its material prosperity With these views he began to scheme a revolution, but his schemes were discovered and he had only just time to escape to the United States Thence he went to England, where he was introduced to Pitt, but chiefly lived with the leading members of the opposition—Fox, Sheridan, and Romilly Finding no help in his revolutionary schemes, he travelled over the greater part of Europe, notably through Austria and Turkey, till he arrived at the court of Russia, where he was warmly received, but from which he was dismissed, though with rich presents, at the demand of the Spanish ambassador, backed up by the envoy of France The news of the dispute between England and Spain about Nootka Sound in 1790 recalled him to England, where he saw a good deal of Pitt, who had determined to make use of him to "insurge the Spanish colonies, but the peaceful arrangement of the dispute again destroyed his hopes In April 1792 he went to Paris, with introductions to Pétion and the leading Girondists, hoping that men who were working so hard for their own freedom might help his countrymen in South America France had too much to do in fighting for its own freedom to help others, but Miranda's friends sent him to the front with the rank of general of brigade He distinguished himself under Dumouriez, was intrusted in February 1793 with the conduct of the siege of Maestricht, and commanded the left wing of the French army at the disastrous battle of Neerwinden Although he had given notice of Dumouriez's projected treachery, he was put on his trial for treason on May 12 He was unanimously acquitted, but was soon again thrown into prison, and not released till after the 9th Thermidor He again mingled in politics, and was sentenced to be deported after the struggle of Vendemiaire Yet he escaped, and continued in Paris till the *coup d'etat* of Fructidor caused him finally to take refuge in England He now found Pitt and Dundas once more ready to listen to him, and the latter sent a special minute to Colonel Picton, the governor of Trinidad, to assist General Miranda's schemes in every possible way, but, as neither of them would or could give him substantial help, he went to the United States, where President Adams gave him fair words but nothing more Once more he returned to England, where Addington might have done something for him but for the signature of the peace of Amiens in 1802. At the peace, though in no way amnestied, he returned to Paris, but was promptly expelled by the First Consul, who was then eager to be on good terms with the court of Spain. Disappointed in further efforts to get assistance from England and the United States, he decided to make an attempt on his own responsibility and at his own expense. Aided by two American citizens, Colonel Smith and Mr Ogden, he equipped a small ship, the "Leander," in 1806, and with the help of the English admiral Sir A. Cochrane made a landing near Caracas, and proclaimed the Colombian republic. He had some success, and would have had more had not a false report of peace between France and England caused the English admiral to withdraw his support. At last in 1810 came his opportunity: the events in Spain which brought about the Peninsular War had divided the authorities in Spanish America, some of whom declared for Joseph Bonaparte, others for Ferdinand VII., while others again held to Charles IV. At this moment Miranda again landed, and had no difficulty in getting a large party together who declared a republic both in Venezuela and New Granada or Colombia. But Miranda's desire that all the South American colonies should rise, and a federal republic be formed, awoke the selfishness and pride of individual provincial administrations, and thus weakened the cause, which further was believed to be hateful to heaven owing to a great earthquake on March 26, 1812. The count of Monte Verde, the Bourbon governor, had little difficulty in defeating the dispirited forces of Miranda, and on July 26 the general capitulated on condition that he should be deported to the United States. The condition was not observed, Miranda was moved from dungeon to dungeon and died in 1816 at Cadiz.

There are allusions to Miranda's early life in nearly all memoirs of the time, but they are not generally very accurate. For his trial see Buchez et Roux, *Histoire parlementaire*, xxvii. 26–70. For his later life see Biggs, *History of Miranda's Attempt in South America*, London, 1809; and Yeggasi, *Revolucion de la Columbia*.

MIRANDOLA. See Pico.

MIRKHOND (1433–1498). Mohammed bin Kháwandshah bin Mahmud, commonly called Mirkhwánd or Mirkháwand, more familiar to Europeans under the name of Mirkhond, was born in 1433, the son of a very pious and learned man who, although belonging to an old Bokhara family of Sayyids or direct descendants of the Prophet, lived and died in Balkh. From his early youth he applied himself to historical studies and literature in general. In Herát, where he spent the greater part of his life, he gained the favour of that famous patron of letters, Mir 'Alishir (born 1440), who served his old school fellow the reigning sultan Husain (who as the last of the Timurides in Persia ascended the throne of Herat in 1468) first as keeper of the seal, afterwards as governor of Jurjan. At the request of this distinguished statesman and writer[1] Mirkhond began about 1474, in the quiet convent of Khilasiyah, which his patron had founded in Herat as a house of retreat for literary men of merit, his great work on universal history, the largest ever written in Persian and to the present day an inexhaustible mine of information both to Eastern and Western scholars. It is named *Rauzat ussafá fi sirat ulanbia walmuluk walkhulafa* or *Garden of Purity on the Biography of Prophets, Kings, and Caliphs*. That the author has made no attempt at a critical examination of historical traditions can scarcely be called a peculiar fault of his, since almost all Oriental writers are equally deficient in sound criticism; more censurable is his flowery and often bombastic style, but in spite of this drawback, and although, in our own age, the discovery of older works on Asiatic history has diminished to some extent the value of Mirkhond's *Rauzat*, it still maintains its high position as one of the most marvellous achievements in literature from the pen of one man, and often elucidates, by valuable text-corrections, various readings, and important additions, those sources which have lately come to light. It comprises seven large volumes and a geographical appendix; but internal evidence proves beyond doubt that the seventh volume, the history of the sultan Husain (1438–1505), together with a short account of some later events down to 1523, cannot have been written by Mirkhond himself, who died in 1498. He may have compiled the preface, but the main portion of this volume is probably the work of his grandson, the equally renowned historian Khwandamir (1475–1534), to whom also a part of the appendix must be ascribed.

The following is a summary of the contents of the other six volumes:—Vol. i. Preface on the usefulness of historical studies, history of the creation, the patriarchs, prophets and rulers of Israel down to Christ, and the Persian kings from the mythical times of the Peshdadians to the Arab conquest and the death of the last Sasanian Yazdajird III. in 30 A.H. (651 A.D.). Vol. ii. Mohammed, Abubekr, Omar, 'Othman, and 'Ali. Vol. iii. The twelve imams and the Omayyad and Abbasid caliphs down to 656 A.H. (1258 A.D.). Vol. iv. The minor dynasties contemporary with and subsequent to the Abbasids, down to 778 A.H. (1376 A.D.), the date of the overthrow of the Kurds by Timur. Vol. v. The Moghuls down to Timur's time. Vol. vi. Timur and his successors down to Sultan Husain's accession in 873 A.H. (1468 A.D.). The best accounts of Mirkhond's life are De Sacy's "Notice sur Mirkhond" in his *Memoires sur diverses antiquites de la Perse*, Paris, 1793; Jourdain's "Notice de l'histoire universelle de Mirkhond" in the *Notices et Extraits*, vol. ix., Paris, 1812 (together with a translation of the preface, the history of the Ismailians, the conclusion of the sixth volume, and a portion of the appendix); Elliot, *History of India*, vol. iv. p. 127 sq.; Morley, *Descriptive Catalogue*, London, 1854, p. 30 sq.; Rieu, *Cat. of Persian MSS. of the Brit. Mus.*, vol. i., London, 1879, p. 87 sq. Mirkhond's patron, Mir Alishir, to whom the Rauzat is dedicated, died three years after him (1501).

Besides the lithographed editions of the whole work in folio (Bombay, 18[illegible]3 and Teheran, 18[illegible]) and a Turkish version (Constantinople, 1842), the following portions of Mirkhond's history have been published by European Orientalists: *Early Kings of Persia*, by D. Shea (London, 18[illegible]) (Oriental Translation Fund), *L'Histoire de la dynastie des Sassanides*, by S. de Sacy (in the above mentioned *Memoires*); *Histoire des Sassanides* (texte Persan) by Jaubert (Paris, 184[illegible]); *Historia priorum regum Persarum*, Pers. and Lat., by Jenisch (Vienna, 1782); *Mirchondi historia Tahiridarum*, Pers. and Lat., by Mitscherlik (Gottingen, 1814; 2d ed., Berlin, 1819); *Historia Samanidarum*, Pers. and Lat., by Wilken (Gottingen, 1808); *Histoire des Samanides*, translated by Defremery (Paris, 1845); *Historia Ghaznevidarum*, Pers. and Lat., by Wilken (Berlin, 18[illegible]); *Geschichte der Sultane aus dem Geschlecht Bujeh*, Pers. and German, by Wilken (Berlin, 1835), followed by Erdmann's *Erlauterung und Erganzung* (Kazan, 1836); *Historia Seldschuckidarum*, ed. Vullers (Giessen, 18[illegible]), and a German translation by the same; *Histoire des Sultans du Kharezm*, in Persian, by Defremery (Paris, 1842); *History of the Atabeks of Syria and Persia*, in Persian, by W. Morley (London, 1848); *Historia Ghuridarum*, Pers. and Lat., by Mitscherlik (Frankfurt, 1818); *Histoire des Sultans Ghourides*, translated into French by Defremery (Paris, 1844); *Vie de Djenghiz Khan*, in Pe[illegible]ert (Paris, 1841) (see also extracts from the same [illegible]th volume in Fr[illegible]en by Langlè in vol. v. of *Notices et Extraits*, Paris, 1[illegible]9, [illegible] Hammer in *Sur les origines russes* (St Petersburg, 1825, p. [illegible]2 sq.)); Timur's Expedition against Toktamish Khan, Persian and French, by Charmoy in *Memoires* [illegible] (18[illegible], ii. [illegible]031 and 441–471). (H. E.)

MIROPOLIE, a town of Russia, situated in the government of Kursk, district of Suja, 83 miles south-west of Kursk and 25 miles from the Sumy railway station. It is supposed to have been founded in the 17th century, when it was fortified against the raids of Tartars. The fertility of the soil led to the settlement of large villages close by the fort, and the 10,800 inhabitants of this town are still engaged mostly in agriculture. There is also an extensive manufacture of boots.

MIRROR. It is only since the early part of the 16th century that mirrors have become articles of household furniture and decoration. Previous to that time—from the 12th to the end of the 15th century—pocket mirrors or small hand mirrors carried at the girdle were indispensable adjuncts to ladies' toilets. The pocket mirrors consisted of small circular plaques of polished metal fixed in a shallow circular box, covered with a lid. Mirror cases were chiefly made of ivory, carved with relief representations of love or domestic scenes, hunting, and games, and sometimes illustrations of popular poetry or romance Gold and silver, enamels, ebony, and other costly materials were likewise used for mirror cases, on which were lavished the highest decorative efforts of art workmanship and costly jewelling The mirrors worn at the girdle had no cover, but were furnished with a short handle In 625 Pope Boniface IV sent Queen Ethelberga of Northumbria a present of a silver mirror, and there is ample evidence that in early Anglo Saxon times mirrors were well known in England It is a remarkable fact that on many of the sculptured stones of Scotland, belonging probably to the 7th, 8th, or 9th century, representations of mirrors, mirror cases, and combs occur

---

[1] Mir Alishir not only excelled as poet both in Chaghatai, in which his epopees gained him the foremost rank among the classic writers in that language, and in Persian, but composed an excellent tadhkirah or biography of contemporary Persian poets.

The method of backing glass with thin sheets of metal for mirrors was well known in the Middle Ages at a time when steel and silver mirrors were almost exclusively employed Vincent de Beauvais, writing about 1250, says that the mirror of glass and lead is the best of all "quia vitrum propter transparentiam melius recipit radios It is known that small convex mirrors were commonly made in southern Germany before the beginning of the 16th century, and these continued to be in demand under the name of bull's eyes (*Ochsen Augen*) till comparatively modern times They were made by blowing small globes of glass into which while still hot was passed through the pipe a mixture of tin antimony, and resin or tar When the globe was entirely coated with the metallic compound and cooled it was cut into convex lenses, which of course formed small but well defined images It appears that attention was drawn to this method of making mirrors in Venice as early as 1317 in which year a "Magister de Alemania who knew how to work glass for mirrors, broke an agreement he had made to instruct three Venetians, leaving in their hands a large quantity of mixed alum and soot for which they could find no use

It was, however, in Venice that the making of glass mirrors on a commercial scale was first developed and that enterprising republic enjoyed a rich and much prized monopoly of the manufacture for about a century and a half In 1507 two inhabitants of Murano, representing that they possessed the secret of making perfect mirrors of glass, a knowledge hitherto confined to one German glass house obtained an exclusive privilege of manufacturing mirrors for a period of twenty years In 1564 the mirror makers of Venice, who enjoyed peculiar privileges, formed themselves into a corporation The products of the Murano glass houses quickly supplanted the mirrors of polished metal, and a large and lucrative trade in Venetian glass mirrors sprang up They were made from blown cylinders of glass which were slit, flattened on a stone, carefully polished, the edges frequently bevelled, and the backs "silvered by an amalgam The glass was remarkably pure and uniform, the "silvering bright, and the sheets sometimes of considerable dimensions In the inventory of his effects made on the death of the great French minister Colbert is enumerated a Venetian mirror 46 by 26 inches in a silver frame, valued at 8016 livres, while a picture by Raphael is put down at 3000 livres

The manufacture of glass mirrors, with the aid of Italian workmen, was practised in England by Sir Robert Mansel early in the 17th century, and about 1670 the duke of Buckingham was concerned in a glass work at Lambeth where flint glass was made for looking glasses These old English mirrors, with bevelled edges in the Venetian fashion, are still well known

The Venetians guarded with the utmost jealousy the secrets of their varied manufactures, and gave most exceptional privileges to those engaged in such industries By their statutes any glassmaker carrying his art into a foreign state was ordered to return on the pain of imprisonment of his nearest relatives, and should he disobey the command emissaries were delegated to slay the contumacious subject In face of such a statute Colbert attempted in 1664, through the French ambassador in Venice, to get Venetian artists transported to France to develop the two great industries of mirror making and point lace working The ambassador, the bishop of Béziers, pointed out that to attempt to send the required artists was to court the risk of being thrown into the Adriatic, and he further showed that Venice was selling to France mirrors to the value of 100,000 crowns and lace to three or four times that value Notwithstanding these circumstances, however, twenty Venetian glass mirror makers were sent to France in 1665, and the manufacture was begun under the fostering care of Colbert in the Faubourg St Antoine, Paris But previous to this the art of blowing glass for mirrors had been actually practised at Tour la Ville, near Cherbourg, by Richard Lucas, Sieur de Nehou, in 1653, and by the subsequent combination of skill of both establishments French mirrors soon excelled in quality those of Venice The art received a new impulse in France on the introduction of the making of plate glass, which was discovered in 1691 The St Gobain Glass Company attribute the discovery to Louis Lucas of Nehou, and over the door of the chapel of St Gobain they have placed an inscription in memory of "Louis Lucas qui inventa in 1691 le methode de couler les glaces et installa la manufacture en 1695 dans le chateau de Saint Gobain

Manufacture —The term silvering as applied to the formation of a metallic coating on glass for giving it the properties of a mirror was till quite recently a misnomer seeing that till about 1840 no silver was used in the process Now however a large proportion of mirrors are made by depositing on the glass a coating of pure silver and the old amalgamation process is comparatively little used

The process of amalgamation consists in applying a thin amalgam of tin and mercury to the surface of glass which is done on a perfectly flat and horizontal slab of stone bedded in a heavy iron bound woolen frame with a gutter running round the outer edge On the surface of this table which must be perfectly smooth and level is spread a sheet of thin tin foil somewhat larger than the glass to be operated on and after all folds and creases have been completely removed by means of stroking and beating with a covered wooden rubber the process of quickening the foil is commenced A small quantity of mercury is rubbed lightly and quickly over the whole surface and the scum of dust impure tin and mercury is taken off Mercury is then poured upon the quickened foil until there is a body of it sufficient to float the glass to be silvered (about ¼ inch deep) and the edge at one of the sides having been cleared of the scum peculiar to mercury, the glass (scrupulously cleaned simultaneously with the above operations) is slid from that side over the surface of the mercury Weights are placed over the surface until the greater part of the amalgamated mercury is pressed out, the table is then tilted diagonally by means of dumb screws and all superfluous mercury finds its way to the gutter The glass is left twenty four hours under weights it is then turned over silvered side up and removed to a drainer with inclining shelves, where by slow degrees, as it dries and hardens it is brought to a vertical position which in the case of large sheets may not be arrived at in less than a month This process yields excellent results producing a brilliant silver white metallic lustre which is only subject to alteration by exposure to high temperatures, or by contact with damp surfaces but the mercurial vapours to which the workmen are exposed give rise to the most distressing and fatal affections

In 1835 Baron Liebig observed that on heating aldehyde with an ammoniacal solution of nitrate of silver, in a glass vessel a brilliant deposit of metallic silver was formed on the surface of the glass To this observation is due the modern process of silvering glass In practice the process was introduced about 1840, and it now carried on, with several modifications, in two distinct ways,

[illegible]

to be silvered is cleaned thoroughly with wet whiting, then washed with distilled water, and prepared for the silver with a sensitizing solution of tin, which is well rinsed off immediately before its removal to the silvering table The table being raised to the proper temperature, the glass is laid, and the silvering solution at once poured over it, before the heat of the table has time to dry any part of the surface of the glass. The solution used is prepared as follows:—in half a litre of distilled water 100 grammes of nitrate of silver are dissolved; to this there is added of liquid ammonia (sp. gr. 0.880) 62 grammes; the mixture is filtered, and made up to 8 litres with distilled water, and 7.5 grammes of tartaric acid dissolved in 30 grammes of water are mixed with the solution. About 2.5 litres are poured over the glass for each superficial metre to be silvered. The metal immediately begins to deposit on the glass, which is maintained at about 40° C. (104° F.), and in little more than half an hour a continuous coating of silver is formed. The silvered surface is then cleaned by very cautiously wiping with a very soft chamois rubber, and treated a second time with a solution like the first, but containing a double quantity of tartaric acid. This solution is applied in two portions, and thereafter the glass is once more carefully cleared of all unattached silver and refuse and removed to a side room for backing up.

In silvering by the cold process advantage is taken of the power of inverted sugar to reduce the nitrate of silver. This process has been adopted for the silvering of mirrors for astronomical telescopes, notably for Leverrier's great telescope in the Paris Observatory. For ordinary mirror silvering the following is the process recommended by H. E. Benrath. Two solutions are prepared, the first of which contains the silver salt, and the second the sugar preparation. For the silver solution 800 grammes of nitrate of silver and 1200 grammes of nitrate of ammonium are dissolved in 10 litres of water, and 1.3 kilos of pure caustic soda in 10 litres of water, and of each of these solutions 1 litre is added to 8 litres of water, which is allowed to rest till the sediment forms and then decanted. The second solution—inverted sugar—is prepared by dissolving 150 grammes of loaf sugar with 15 grammes of vinegar in 0.5 litre of water, and boiling the solution for half an hour. After cooling it is made up with water to 4200 cubic centimetres. The silvering is done on horizontal tables in a well lighted and moderately heated apartment, and the glass is cleaned with scrupulous care. For each square centimetre of glass operated on 15 cubic centimetres of the silver solution above described are measured out, and from 7 to 10 per cent. of the solution of inverted sugar is added, both being quickly stirred together and poured rapidly and evenly over the glass. The reduction immediately begins, and the solution exhibits tints passing through rose, violet, and black, till in about seven minutes it again becomes transparent and the deposit of metal is complete. This first deposit is extremely thin, and allows the transmission of bluish rays. The exhausted solution with floating and unattached dust-like granules of silver is carefully wiped off, the silvered surface washed with distilled water and again treated with the mixed solutions to the extent of half the quantity used in the first application. The finished surface is wiped and washed in the most thorough manner,—for the least trace of caustic soda left would destroy the mirror. The further processes are the same in both methods of silvering.

The deposit of silver on glass is not so adherent and unalterable under the influence of sunlight and sulphurous fumes as the tin mercury amalgam, and moreover real silvered glass has a slightly yellowish tinge. These defects have been overcome by a process introduced by M. Lenoir, which consists of brushing over the silvered surface with a dilute solution of cyanide of mercury, which instantaneously forming a kind of amalgam renders the deposit at once much whiter and more firmly adherent than before. To protect the thin metallic film from mechanical injury and the chemical action of gases and vapours, it is coated with shellac or copal varnish, over which when dry are applied two coatings of red lead paint.

Platinum Mirrors.—A cheap process of preparing mirror glass is to some extent prosecuted in France, whereby a thin but very adherent deposit of platinum is formed on the glass. A solution of chloride of platinum with a proportion of litharge and borate of lead dissolved in essential oil of spike is applied with a brush to well cleaned glass, which is then placed on edge in a muffle furnace, and the platinum is thus burned in, forming an exceedingly thin but brilliant metallic backing having a somewhat grey lustre. It is used only for the lids of cheap boxes, toys, ornamental letters, &c.

Magic Mirrors.—Hand mirrors of metal are still in common use in Oriental countries, and especially in Japan and China they continue to be the prevalent form of looking-glass. In the former country indeed bronze mirrors are articles of the greatest importance in the generally meagre furnishing of houses, and besides possess a religious significance. They have been known and used from the most remote period, mention of them being found in Chinese literature of the 9th century. The (reputed) first made Japanese mirror preserved at Ise, is an object of the highest veneration in Japan, and an ancient mirror connected with which is a tradition to the effect that is was given by the sun goddess at the foundation of the empire, is a principal article of the Japanese regalia. The mirrors of Japan vary in form and size, but in general they consist of thin disks, from 3 to 12 inches in diameter, of speculum metal with handles cast in one piece. The polished face of the mirror is slightly convex in form, so that a reflected image is seen proportionately reduced in size; the back of the disk is occupied with characteristic Japanese ornamentation and inscriptions in bold relief, and its rim is also raised to the back. Much attention has been attracted to these mirrors by a singular physical peculiarity which in a few cases they are found to possess. These are known as magic mirrors from the fact that when a strong beam of light is reflected from their smooth and polished surface, and thrown on a white screen an image of the raised ornaments and characters on the back of the mirror is formed with more or less distinctness in the disk of light on the screen. This peculiarity has at no time been specially observed by the Japanese, but in China it attracted attention as early as the 11th century, and mirrors possessed of this property sell among the Chinese at ten or even twenty times the price sought for the ordinary non-sensitive examples. The true explanation of the magic mirror was first suggested by the French physicist Person, who observed that the reflecting surface of the mirrors was not uniformly convex, the portions opposite relief surfaces being plane. Therefore, as he says, "the rays reflected from the convex portion diverge and give but a feebly illuminated image, while on the contrary the rays reflected from the plane portions of the mirror preserve their parallelism, and appear on the screen as an image by reason of their contrast with the feebler illumination of the rest of the disk." That such differences of plane in the mirror surface arise is an accidental circumstance due to the manner in which it is prepared, a process explained by Professors Ayrton and Perry, by whom ample details of the history, process of manufacture, and composition of Oriental mirrors have been published. A preliminary operation in polishing the surface consists of scoring the cast disk in every direction with a sharp tool. The thicker portions with relief ornament offer more resistance to the pressure of the tool than the thin flat portions, which tend to yield and form at first a concave surface, but this by the reaction of its elasticity rises afterwards and forms a slightly convex surface, while the more rigid thick portions are comparatively little affected. This irregularity of surface is inconspicuous in ordinary light, and does not visibly distort images; but when the mirror reflects a bright light on a screen the unequal radiation renders the minute differences of surface obvious. The ingenious theory of Person has been established by experiments communicated by M. Govi to the academy of Turin in 1864-65, and more recently by investigations of MM. Bertin and Dubosq. See *Annales de Chimie et de Physique* (5th ser., vol. xx.). (J. PA.)

Ancient Mirrors.

The mirror of classical antiquity (κατοπτρον, speculum) was a thin disk of bronze slightly convex on one side and polished, usually provided with a handle, sometimes mounted on a stand in the form of a female figure (see COSTUME, vol. vi. p. 453, fig. 1), sometimes fixed inside a circular bronze case. The common size is that of an ordinary hand mirror. Examples large enough to take in the whole figure appear to have been rare. Mirrors of glass are mentioned, and though none of them have been found their existence need not be questioned altogether, since the process of silvering occasionally employed on bronze mirrors suggests that an analogous process may have been applied to glass. But the very large number of mirrors still existing from antiquity shows that bronze was the regular material employed. The alloy known as speculum, producing a very hard metal with great reflecting power, is comparatively seldom met with. Silver mirrors are mentioned, but none have as yet been found.

The principal feature of ancient mirrors, especially those of Etruria, is the design incised on the back (see ETRURIA, vol. viii. p. 643). While twelve incised specimens are all that are as yet known from Greece, the number found in Etruria must be nearly a thousand. As a rule the subjects incised are taken from Greek mythology and legend, the names of the persons represented being frequently added in Etruscan letters and orthography. In most cases the style of drawing, the types of the figures, and the manner of composing the groups are true to the characteristics of Greek art. Some may have been imported from Greece, but the greater number appear to have been more or less faithfully imitated from such designs as occurred on the almost innumerable painted Greek vases which the Etruscans obtained from Greece. Even where distinctly Etruscan figures are introduced, such as the heroes Ælius and Cælius Vibenna on a mirror in the British Museum, Greek models are followed. The characteristics of Greek art here referred to date from a little before 400 B.C., and last for some time after. In this period would fall the majority of the Etruscan mirrors, and to this period also belong the Greek incised mirrors, among which may be mentioned for their beauty one representing Leucas and Corinthus inscribed with their names (engraved *Monuments Grecs*, 1873, pl. 3, published by the Association pour l'encouragement des Études Grecques), and another in the British Museum (*Gazette Arch.*, ii. pl. 27), on the back of which is a figure of Eros which has been silvered over. With this last mentioned mirror was found the bronze case used to contain it,